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Biological Services Program

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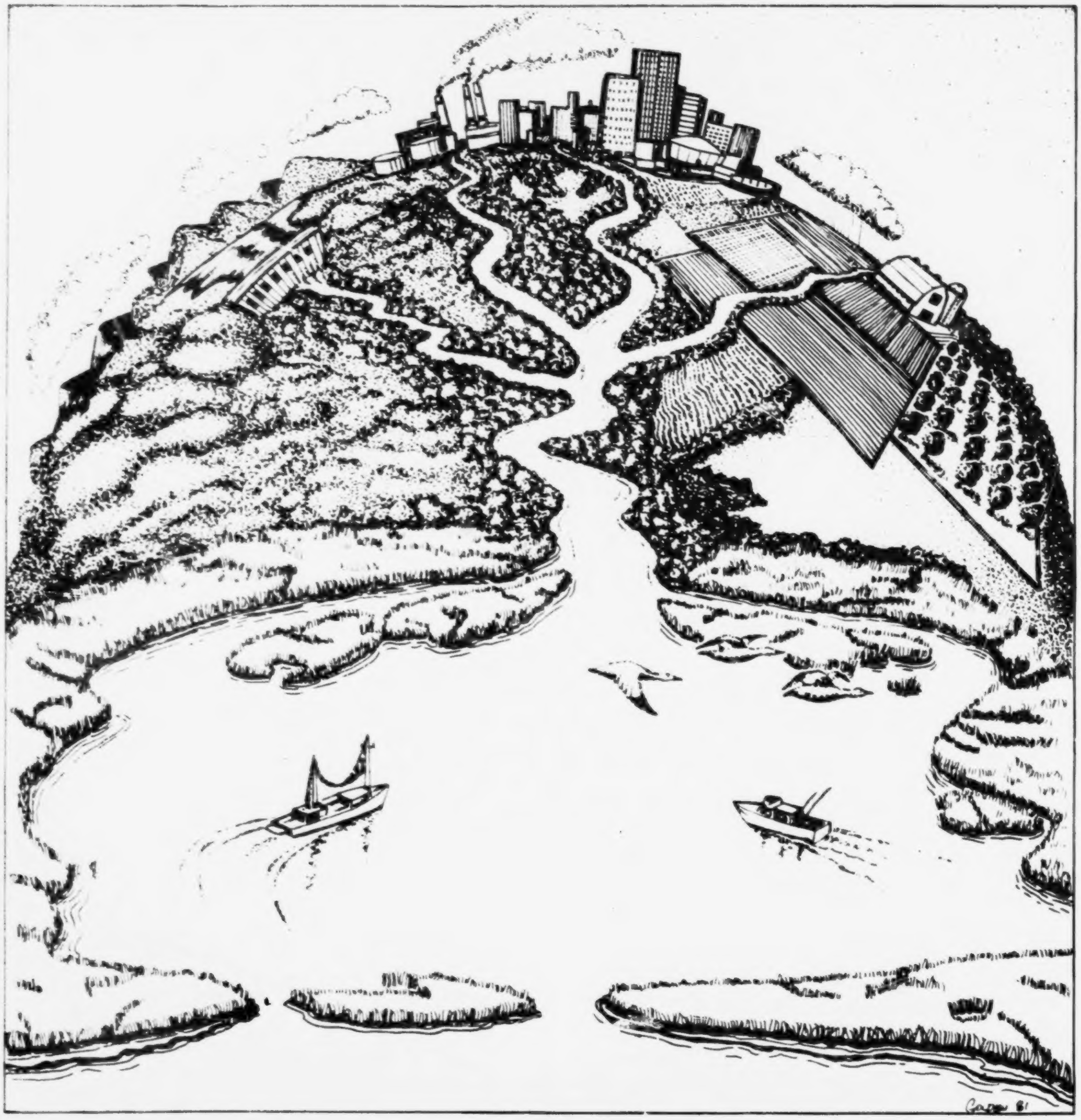
Proceedings of the National Symposium on Freshwater Inflow to Estuaries

VOLUME I



Fish and Wildlife Service

U.S. Department of the Interior

The Biological Services Program was established within the U.S. Fish and Wildlife Service to supply scientific information and methodologies on key environmental issues that impact fish and wildlife resources and their supporting ecosystems. The mission of the program is as follows:

- To strengthen the Fish and Wildlife Service in its role as a primary source of information on national fish and wildlife resources, particularly in respect to environmental impact assessment.
- To gather, analyze, and present information that will aid decisionmakers in the identification and resolution of problems associated with major changes in land and water use.
- To provide better ecological information and evaluation for Department of the Interior development programs, such as those relating to energy development.

Information developed by the Biological Services Program is intended for use in the planning and decisionmaking process to prevent or minimize the impact of development on fish and wildlife. Research activities and technical assistance services are based on an analysis of the issues, a determination of the decisionmakers involved and their information needs, and an evaluation of the state of the art to identify information gaps and to determine priorities. This is a strategy that will ensure that the products produced and disseminated are timely and useful.

Projects have been initiated in the following areas: coal extraction and conversion; power plants; geothermal, mineral and oil shale development; water resource analysis, including stream alterations and western water allocation; coastal ecosystems and Outer Continental Shelf development; and systems inventory, including National Wetland Inventory, habitat classification and analysis, and information transfer.

The Biological Services Program consists of the Office of Biological Services in Washington, D.C., which is responsible for overall planning and management; National Teams, which provide the Program's central scientific and technical expertise and arrange for contracting biological services studies with states, universities, consulting firms, and others; Regional Staffs, who provide a link to problems at the operating level; and staffs at certain Fish and Wildlife Service research facilities, who conduct in-house research studies.

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FWS/OBS-81/04
October 1981

PROCEEDINGS
OF
THE NATIONAL SYMPOSIUM
ON
FRESHWATER INFLOW TO ESTUARIES

Volume I

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Disclaimer

The findings in this report are not to be construed as an official U.S. Fish and Wildlife Service position unless so designated by other authorized documents.

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NATIONAL SYMPOSIUM ON FRESHWATER INFLOW TO ESTUARIES

PREFACE

The First National Symposium on Freshwater Inflow to Estuaries sponsored by the U.S. Fish and Wildlife Service, was held in San Antonio, Texas on 9-12 September 1980. The Symposium focused attention on the importance of estuarine ecosystems to our Nation and their dependency on freshwater inflows. Estuaries have been degraded in many coastal areas and much of the documented damage has been attributed to alteration and reductions of freshwater inflow. The symposium was organized to accomplish the following objectives:

1. Identify the issue of estuarine freshwater inflow requirements as a National Environmental Problem.

2. Describe some values of estuarine ecosystems to the Nation for food, recreation, and fish and wildlife habitats.

3. Review models or methodologies for predicting the effects of altering freshwater inflow on estuarine ecosystem functions, processes, and production.

4. Develop recommendations that bring the freshwater inflow needs of estuaries more effectively into inland and coastal planning.

Efforts were made to include participation of government leaders, engineers, ecologists, lawyers, economists, hydrologists, and others interested in estuaries. We accomplished all of the stated objectives to some degree. These Proceedings are an initial effort to develop a data base and to bring freshwater inflow into local, state, regional and federal planning and management processes. Participants emphasized that there was much concern for protecting and restoring water needs of estuaries. Lack of planning was attributed to inadequate baseline data and models or methods of applying the data. The Proceedings are organized by chapters that closely follow the Symposium's sessions. The discussion and some of the plenary presentations were edited from recorded material.

Comprehensive and effective planning for freshwater inflow to estuaries requires that all inland land- and water-use decisions within a watershed that empties into the ocean should be made with a clear understanding of the consequences of these decisions on estuarine ecosystems. Although this goal will be difficult to implement, it is based upon the widely recognized ecological fact that all the ecosystems within a watershed are tied together.

Several recommendations to protect and restore estuarine ecosystems were developed from plenary sessions, technical papers, and discussions. These recommendations will be forwarded to agencies responsible for their implementation.

Estuaries probably have been affected more by development and industry than any other ecosystem in our Nation because many of our largest cities are located either on major rivers providing fresh water to estuaries or on estuaries themselves. Estuaries are one of the best ecosystems for monitoring our success in integrating commercial development and environmental protection.

Norman G. Benson
Paul F. Fore
Co-Chairmen

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ACKNOWLEDGMENTS

The goal, objectives, and scope of the Symposium were developed by a steering committee consisting of the following:

Norman G. Benson, U. S. Fish and Wildlife Service (FWS), Co-chairman
Paul Fore, FWS, Co-chairman
James Barkuloo, FWS
Keith Bayha, FWS
Bert Brun, FWS
John Byrne, FWS
Ralph Cross, University of Southern Mississippi
Nicholas Funicelli, FWS
B.D. King, FWS
Steven Goodbred, FWS
Robert Hayden, FWS
Joseph Kathrein, FWS
William Lindall, National Marine Fisheries Service
Norval Netsch, FWS
Ted Robinson, U.S. Army Corps of Engineers
Richard Wade, FWS (retired)

Myron Webb, Symposium Coordinator, University of Southern Mississippi, handled the administrative work.

Session chairmen introduced speakers, directed discussion, and assisted in editing the papers. Those session chairmen that were not on the steering committee were:

Robert Stewart, FWS
John Clark, Conservation Foundation
Gordon Thayer, National Marine Fisheries Service
Gilbert Radonski, Sport Fishing Institute
Robert Livingston, Florida State University
Charles Caillouet, National Marine Fisheries Service
William Perret, Louisiana Wildlife and Fisheries Department
Rezneat Darnell, Texas A&M University
Emmet Gloyna, U.S. Water and Power Resource Service
Wiley Kitchens, FWS
Gerald Johns, California State Water Resources Board
Carroll Cordes, FWS

The Sport Fishery Research Foundation and the Environmental Quality Committee of the American Fishing Tackle Manufacturers Association provided travel funds for some invited speakers.

Preparation and publication of the Proceedings were supported by the U.S. Department of the Interior, Fish and Wildlife Service, Coastal Ecosystems Project.

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PLENARY SESSION

ESTUARIES AND FRESHWATER INFLOW

Chaired by

Dr. Robert Stewart, Leader,
National Coastal Ecosystems Team
Slidell, Louisiana

INTRODUCTION

Robert Stewart
U.S. Fish and Wildlife Service
National Coastal Ecosystems Team

Our purpose here today is to begin to grapple with some of the issues. These are not new issues. They have been around for some time, but perhaps we can take a fresh look at them. Issues deal with freshwater inflow to estuaries where the quantity and quality of water that flows into estuaries varies considerably.

The purpose here in convening this symposium is twofold. First, we need to gain a better understanding of what the issues are; and, second, we need to arrive at some solutions or potential solutions and recommendations that will permit us to deal with the issues. There are no guiding rules for this symposium other than having a rather lively discussion and to reach some agreement on policy issues, technical issues, and on legal issues or new laws by the end of this symposium, so that we can come forward with strong recommendations.

WELCOMING ADDRESS

Jerry L. Stegman
Acting Regional Director
Region Two
U. S. Fish and
Wildlife Service

On behalf of the U. S. Fish and Wildlife Service (FWS), it is my pleasure to welcome all of you to the first National Symposium on Freshwater Inflow to Estuaries.

As I looked over the program, I was impressed by the comprehensive subject matter that has been included. I was also pleased to note the diverse participation by representatives of numerous Federal, state, and private agencies. I am sure these ingredients will combine to provide an excellent symposium.

You may have asked yourself, how is it that a Fish and Wildlife Service Regional Office located in Albuquerque, New Mexico, is interested in co-hosting a symposium of this type. The answer is that Texas falls within the Albuquerque Region's jurisdictional boundaries. Some of the most biologically productive coastal waters, barrier islands and salt marshes in the Nation occur along the Texas coast. We are concerned with protecting this valuable habitat from man's encroachment.

The Fish and Wildlife Service and the State of Texas recognize many major threats to the Texas coastline. Water-development projects are slowly but surely reducing the amount of fresh water reaching the estuaries. Channelization and dredge and fill projects are destroying valuable coastal environments. Oil and gas and coal development are destroying valuable wet lands and are polluting these areas with toxic chemicals. For example, last year's IXTOC-I oil spill discharged 3 million barrels which translates into 126 million gallons of oil into the western Gulf of Mexico. Much of this found its way to the Texas coast. There is strong evidence that agricultural pesticides are reaching the near coastal areas.

All of these and other activities threaten and degrade valuable coastal fish and wildlife habitats and the commercial and recreational values associated with them.

Region 2, in cooperation with the State of Texas, has implemented two major thrusts for habitat preservation on the Texas coast.

o The first is our active Coastal Land Acquisition Program. For instance, since 1977, the FWS has acquired approximately 54,000 acres of prime coastal prairie marsh (composed of salt, brackish, and freshwater marshes). These areas provide irreplaceable wintering habitat for waterfowl, other migrating birds, resident wildlife, and nursery grounds for finfish and shellfish.

o The second is our activities under the Fish and Wildlife Coordination Act, wherein we review and report on various types of Federal water development projects, and review permit applications by private groups or individuals seeking Federal permits for various types of private development.

For several years now, Region 2 has also identified the problem of reduced freshwater inflow to Texas estuaries as our number one regional environmental problem. We have realized that there is a need for more comprehensive water resource planning in order to preserve freshwater inflows and to protect valuable fish and wildlife habitats. Consequently, the Director of the Service gave this region the lead to investigate environmental problems specific to the Texas coast. In 1977 and 1978, we contracted two studies designed to determine, in part, the freshwater needs of fish and wildlife resources in Nueces/Corpus Christi Bay and in Matagorda Bay, Texas. The objectives of these studies were to develop water management plans and recommendations to assist Federal and state agencies in future development planning, and thus insure the future biological productivity of these bay systems. The study designs and progress have been closely coordinated with state and other Federal agencies. The Nueces-Corpus Christi Study is essentially complete and the Matagorda Bay Study is scheduled for completion in late 1981.

In 1979, as an outgrowth of these studies, our Region was assigned the lead role in developing a National Freshwater Inflow Budget Issue Paper in cooperation with the National Coastal Ecosystems Team and the other segments of the FWS. The purpose of this proposal was to conduct similar studies of all remaining bay systems in the entire United States. However, because of funding restraints, a national, multi-year study was not established at that time. But that pioneering effort set the stage for this week's national symposium.

In Texas, we have also identified Galveston Bay as the next bay that needs to be studied for freshwater inflow needs. The Office of Environment (FWS) is presently preparing a budget issue paper on Galveston Bay which will describe the serious problems associated with energy development, water resource development, and pollution and their relationships to freshwater inflow needs of that bay system.

In summary, the FWS is proud of its past record and efforts on this issue of estuarine freshwater inflow needs. We also pledge our continued effort and support.

During your stay at the symposium, if there is anything we can do to assist you, please contact one of our FWS Regional employees. We'll do everything possible to assist you and to make this symposium one of the great milestones in our common goal to preserve the Nation's valuable coastal estuaries for future generations.

KEYNOTE ADDRESS: HOW CONGRESS VIEWS ESTUARIES

Kieth Ozmore

Environmental Consultant to Congressman Robert Eckhardt, Texas

First, I want to thank the U.S. Fish and Wildlife Service for the invitation to present the keynote address at this most important symposium, and to commend the Coastal Ecosystems Project for sponsoring it. In my estimation, there is no more important area in the Nation than its estuaries, and none which faces greater dangers.

My presentation today will deal primarily with two facets of the situation: the view from a congressional perspective; and the view of the value of those estuaries, from a member of Congress who represents a District which borders on the Galveston Bay System, one of the most productive estuarine systems in America.

I note that my presentation is entitled "How Congress Views Estuaries." I wish that I could tell you this morning that Congress views the estuaries the same as you and I. But that is simply not the case. It was not so long ago, when the House was considering a bill to gut the Section 404 permit program, that a prominent, influential member of Congress made this statement on the floor: "To hell with fish ... let's look out for people."

What this member failed to recognize is that when we are looking out for shrimp, menhaden, blue crab, speckled trout and redfish, we are, indeed, looking out for people--just the same as we are looking out for people when we pass legislation to help the farmer make his land more productive for protein matter. Most of those attending this symposium already know that our estuaries are extremely productive of protein. Our problem is how to deliver this information to those public officials far inland--Denver, Frankfort, or Des Moines.

Several years ago, when Texas A & M University inaugurated its course "Special Topics in Coastal Zone Management," Robert Knecht, at that time Director of the Federal Office of Coastal Zone Management, was one of the guest lecturers. A member of my staff who had recently attended a national oceanic conference along with Mr. Knecht in Seattle, Washington, was driving the agency official to A & M and they got into a conversation on the importance of coastal zone management. My staff member commented that this Nation did not need coastal zone management or oceanic conferences in Seattle, Boston and Savannah--it needed such conferences in far-flung inland cities, and Mr. Knecht agreed.

In looking over the preliminary program for this symposium, I am quite impressed at the expertise of those making presentations. It is encouraging that this symposium is being held inland--but not too far inland. In fact, hundreds of San Antonio residents commute back and forth to the coast for salt-water fishing and waterfowl hunting. I would like to suggest that additional symposia be held, but that they be scheduled perhaps in state capitals of inland states so that you educate not only members of Congress from those states, but state and local officials as well. I suspect that the vast majority of residents of those areas do not have the faintest idea where shrimp come from or how important it is to preserve their nursery habitat.

Let me hasten to add, however, that all the ignorance of our important coastal zone is not restricted to inland areas. A number of years ago, the Texas Parks and Wildlife Commission held a public hearing on how much it should charge for removal of bay bottoms. During the course of the hearing, one man who actually lived on the coast questioned why the state should be involved. He asked the question: "What good is that stinking old marsh, anyway?" Dr. Dan Willard, a botany professor at the University of Texas, was sitting up front, and one could almost see the hackles rise on his neck. He replied: "I would like for the gentleman to know that, acre for acre, 'that stinking old marsh' produces more protein than the richest acre of farmland in the Midwest."

While many members of Congress may not fully know the value of our coastal wetlands, I suspect that many of our problems lie with the parochial positions taken by some members. We have too few members who take a broad national overview of issues which we deal with every week. Their first, and sometimes only question is: "How does it affect my constituency?" For instance, today much of our energy is being produced from the continental shelf, and even a greater share probably will come from that area in the future. Inland officials read where the Sierra Club or Audubon Society has sued to prohibit drilling for oil and gas in an estuary. Their first reaction is that environmentalists are trying to keep constituents from driving their gas-guzzling automobiles and trying to freeze them in the dark just to preserve the habitat of a dickey bird. Which gets me now to the second phase of my presentation.

I have long appreciated the beauty of a saltwater marsh and the stillness of an East Texas hardwood bottom. But in recent years I have come to the conclusion that if we are to preserve any of such beauty, we almost have to put a price tag on it. It is too difficult to place a dollar mark on the value that one derives from the aesthetic enjoyment of the outdoors. It should not be that way, but it is. Tellico Dam has shown us that we must have economic justification for preservation, and in most cases I think we can justify our positions. Certainly we can when it comes to protecting the oceans and their bounties.

One of the first concepts to be recognized when we begin to look at the dollar value of any resource is the long-term gain vs. the short-term. The first major battle I became involved in was in 1963 when the Texas Parks and Wildlife Commission amended two long-held rules on dredging of commercial oyster shell in Galveston Bay, posing threats to our oyster fishermen. Our argument then, and it still is a valid one, is that we must calculate the value of those reefs on a long-term basis, producing oysters year in and year out, and compare their value on a short-term basis as a component for cement or chemical products. We argued that while their value for the latter may be quite high, if we kept the reefs intact and productive, then they would continue to produce oysters decade after decade, just as they have for thousands of years in the past. Their value, then, on a long-term basis would far surpass their short-term value for building roads or for other purposes.

This is no less true for the wetlands which provide nursery grounds for the shrimp, the blue crab, and the finfish. During the past few decades, these areas have been destroyed, bit by bit, a few acres there, and a not so few acres which could have been destroyed had the Wallisville Reservoir project been carried out to completion. As one environmentalist puts it, we have "nickled and dimed our estuaries to death." While I recognize that the subject matter of this symposium is the importance of freshwater inflow, my point is this: if the estuaries are destroyed by dredging and filling, then what good would it do to have the freshwater inflow?

During the battle with the shell dredgers, they made the point that Galveston Bay was so polluted and that so much of it was off limits due to high levels of coliform that they might as well be permitted to dredge out the reefs. My positions was that pollution can be cleaned up, and there would be little point in cleaning up pollution if the entire ecosystem had been damaged beyond repair by its physical impairment. My argument has been borne out as a valid one. Today, the biochemical oxygen demand flow into the Houston Ship Channel is only about 70,000 pounds daily, where a decade ago it was approximately 300,000 pounds. So we must not let permanent destruction go unchecked because a temporary situation prevents their use by mankind.

The economic value of our wetlands can be looked at from two viewpoints: one, its production of commercial species of marine life; and second, its production of species which are harvested by the recreational fishermen. First, let me discuss the shrimp fishery, for this is the one that I know most about. Thousands of residents along the Texas gulf coast make their livelihood, or part of it, from the shrimp fishery. In 1979, shrimpers landed 41,604,000 pounds of this delicacy at Texas ports, worth $153,115,000 ex-vessel value. By the time this harvest reached the dinner tables of America, it was worth about three times that or approximately $500,000,000. Louisiana fishermen landed 50,125,000 pounds, with an ex-vessel value of $115,282,000 or $345,000,000 final value. The other three states fronting on the Gulf of Mexico landed a total of 35,322,000 pounds, ex-vessel value of $109,245,000, or $327,600,000 final retail value.

The total landings from the Gulf of Mexico amounted to 127,049,000 pounds, worth $377,642,000 at boatside, or a whopping $1,133,000,000 dollars final retail value. In the entire nation, only 202,717,000 pounds of shrimp were landed, with an ex-vessel value of $471,573,000. This means, then, that our gulf landings amounted to 62.2 percent of the total American catch and just a little more than 80 percent of the ex-vessel value of the U.S. harvest. Just one little reminder here: all of these shrimp spend some part of their life in the areas that we all are interested in protecting our estuaries.

The second economic value we place on our estuaries is their productivity of species important to the recreational fishery. The two most important of those species are the spotted weakfish, known in Texas as the speckled trout, and the channel bass, which we call the red drum or redfish. Speckled trout spawn in the estuaries, while the redfish spawns just offshore, and their fry go up into the nursery grounds of the estuaries. Moreover, two of the principal food fishes upon which these species depend are also estuarine-dependent. I speak of the shrimp and menhaden.

Today, there are some 600,000 salt-water anglers in Texas. And with the ever-increasing movement to the ocean-front, this number will continue to increase dramatically. In 1975, the U.S. Fish and Wildlife Service Survey indicated that each saltwater angler fished an average of 12 days annually, spending approximately $11.50 per day while fishing. With the 40 percent increase in costs since that time, this means that each of Texas' 600,000 anglers spent about $16 per day, or a total of $192 per year. All told, the expenditures for salt-water fishing in Texas would total $75,200,000 annually, and this does not include the capital outlay for the sportsman's boat, motor, trailer and terminal tackle. Again, on looking at it from a long-term gain basis, this impact upon the Texas coastal economy not only will continue, but it will continue to grow, as the population grows. Destroy our estuaries, and we destroy this important economic value.

I would like to touch for a moment on the subject which you will be discussing here for the next three days--the freshwater inflows into the estuaries. I do not propose to speak as an expert--you will hear from them later. But I do have a few thoughts on the matter. Several years back, when the infamous Texas Water Plan was being proposed, we were told that it would provide a grand total of 2 million acre-feet annually to Texas bays. How generous! I am told that the Galveston Bay system alone needs something like 7 million acre-feet annually to remain productive. Since neither our commercial fisheries nor our sports fisheries are defined as an "industry" they do not legally come in for their share of freshwater flows. But some scheme must be devised to assure that enough freshwater is released from the dams and impoundments to keep our bays productive.

Sometimes I wonder why it would not be feasible to store some of the excessive rainfall during extremely wet years to be released subsequently in extremely dry years, such as we are experiencing now. For instance, in 1972 and 1973 we had something like 72 inches of rainfall in the Trinity River Watershed, where the annual average is about 42 inches. It seemed tragic that this fresh water inflow perhaps was wasted--although we are told that occasional flushings from heavy rainfalls are good for the estuarine systems--but 72 inches? During that period the fresh water reached five miles offshore. I hardly think that kind of flushing is necessary to keep the estuaries healthy. On the other hand, though, how do you store even a portion of that kind of rainfall?

One of our commercial fishing friends, a few years after those floods, came up with a proposal to construct a diversionary canal from the Trinity River, around Houston, to dump the surplus into the Brazos. He never did explain where we were to get the billions of dollars with which to purchase the right-of-way for the canal, nor who was going to foot the bill so that the oyster harvest would not be destroyed by the fresh water.

Is it feasible to store some of the surplus in wet years? How much would we need to store? How much would it cost? Who would pay the cost? These are some of the questions that need answers.

In closing, let me say that we who love our coast are optimists. If we were not optimists, we would have long ago thrown in the towel. But we win a few now and then, such as the significant Wallisville Reservoir project. I hope that this symposium brings happy results, that we can convince our friends that they too have a stake in our coastal wetlands...I hope that you will go away from this symposium with a new dedication, a new hope that is a worthy one--one that will assure a better, fuller life for those coming on behind us.

Again, thank you very much for the opportunity to be a part of this important symposium.

OVERVIEW OF U.S. WATER RESOURCES PLANNING, POLICIES, AND LAWS THAT AFFECT COASTAL AREAS

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Estuaries play a subtle yet vital role in our existence. They are the source of many of life's amenities for all of us on land. And, freshwater inflows play a subtle yet vital role in the existence of the estuary. The delicate balance of fresh water and salt water breeds both the bounty of the estuary and the potential for its destruction. The environment which is formed where a river flows to the sea attracts not only spawning fish, aquatic mammals and shellfish, but also people.

More than half of our Nation's population lives within 50 miles of the coast. Most of that population is concentrated in cities which thrive on or near the mouth of a river--Boston on the Charles, New York on the Hudson, New Orleans on the Mississippi, San Francisco on the Sacramento-San Joaquin. These concentrations of people place great demands on the coastal zone. As a result, our industrial, agricultural, commercial, and recreational needs are threatening the health and productivity of our estuaries.

My purpose in coming here today is not to alert you to the problems surfacing in the coastal zone. Your presence indicates your awareness of these problems. Rather, I am here to lay before you the unbeaten path of U.S. law and policy which, if properly implemented, might lead us toward the goal we recognize today --the proper respect for our estuaries and their lifeblood: the freshwater inflows.

I call the path unbeaten because, although the laws exist and the policy has been enunciated, we have yet to take our first forceful step toward consideration of freshwater inflows and their recipient estuaries. The first piece of legislation to come to mind when mention is made of the coastal zone is, of course, the Coastal Zone Management Act of 1972. Passage of that Act marked congressional recognition of the coastal zone as one of our Nation's prized resources. For management and protection of this resource, Congress naturally looked to the states--the source of local government zoning power. Since localities derive their power to zone from a state enabling act, the state reserves the right to require that each locality respect the needs of the entire state in its individual master plan.

This supervisory function is what Congress sought to fund with the Coastal Zone Management Act. Federal funds assist the states in the development and administration of management programs designed to ensure that the locality respects the interests of the state and that, in turn, the state respects the interests of the nation. This framework seems tailor-made to handle our freshwater inflow concerns. However, National objectives have not been the focus of the plans to date.

Under the CZM program, each participating state must identify the boundaries of its coastal zone, define permissible land and water uses which have a direct and significant impact on the coastal zone, designate areas of particular concern, identify means of state control over land and water uses (including constitutional provisions, statutes, regulations, and judicial decisions), and determine the respective responsibilities of local, state, regional, and interstate agencies.

If participation were any measure of success, there would be cause to rejoice because 31 of the 35 states which are eligible to participate in the CZM program are doing just that. However, compliance with the procedural requirements of the Act does not necessarily ensure that substantial achievement of national coastal zone management goals will be realized.

The Water Policy Task Force on Environmental Statutes noted in its 1979 report that there is lingering doubt about the efficacy of the CZM program. In responce to such criticism, the Office of Coastal Zone Management has offered amendments of its enabling legislation which would serve to clarify the national objectives for the coastal zones and OCZM's authority to condition Federal assistance on the pursuit of those objectives. The President recommended enactment of these amendments in his 1979 Environmental Message. If these amendments were adopted by the Congress, the present patchwork of coastal zone programs may have a chance to become the tightly-knit fabric envisioned by the Congress when it passed the Coastal Zone Management Act in 1972.

Another major piece of legislation which could provide a means for considering freshwater inflows to estuaries is the ubiquitous National Environmental Policy Act (NEPA) of 1969. Certainly the environmental impact statement (EIS) which NEPA requires can and should reflect a proposed project's probable impact on the timing, quality, and quantity of freshwater inflows to estuaries.

One of the major impediments to consideration of these impacts in EISs to date has been a lack of awareness of the freshwater inflow problem. President Carter has already resolved two identity crises which are similar to those suffered by the freshwater inflow and its recipient estuary. In Executive Orders 11988 and 11990, issued in 1977 under NEPA, the National Flood Insurance Act and the Flood Disaster Protection Act, floodplains and wetlands gained national recognition. Their protectors are now perceived as a force to be reckoned with. The WRC, CEQ, and FEMA were assigned the responsibility of assisting the other Federal agencies in their implementation of the orders and in monitoring their effectiveness. Perhaps if estuaries were similarly honored as the subject of an executive order, freshwater inflow would in turn get its fair share of attention.

Of course, the potential may be argued that the existing executive orders are sufficient to encompass protection of estuaries and their freshwater inflows. Afterall, estuaries are a part of the floodplain and inflows do flow in through wetlands. Estuaries are a very special part of the floodplain and special attention must be paid to them. But, the President's articulation of this point in an order to the executive agencies could very well provide the impetus needed to get the inflow problem considered in environmental impact statements issued under NEPA and in other agency decisionmaking.

There remains one further piece of legislation which predates all that I have discussed this far. In 1968, Congress passed what has since been dubbed the Estuary Protection Act. Unfortunately, this is not the name that Congress gave to the act. In fact, Congress did not name the act at all. Ordinarily, that difference would be inconsequential. After all, NEPA has proven to be a potent statute, even though many still call it the National Environmental Protection Act rather than the National Environmental Policy Act. But, in the case of the Estuary Protection Act, the misnomer signifies all that is missing from current U.S. performance on estuaries. The act purposes to "provide a means of considering the need to protect, conserve, and restore estuaries." The act provides for consideration, not protection. In 1970, a study was made pursuant to this act. No protection has ensued. There is a section of the act which has the potential to force Federal agencies to give special consideration to the needs of estuaries. This section provides that "in planning for the use of development of water and land resources all Federal agencies shall give consideration to estuaries and their natural resources, and their importance for commerical and industrial developments, and all projects and reports affecting such estuaries and resources submitted to the Congress shall contain a discussion by the Secretary of the Interior of such estuaries and such resources and the effects of the project on them and his recommendations thereon." Note the delegation of responsibility to the Secretary of the Interior.

The Congress in 1968 clearly gave the Secretary of the Interior the responsibility for administering the act. Since that time, President Nixon transferred responsibility for commerical fisheries from Interior to Commerce, thereby creating the problem of who should administer the Estuary Act. President Nixon issued that reorganization order in 1970. Since then, no action has been taken under the 1968 act.

This conflict between Interior and Commerce over responsibility for the Estuary Act embodies all of the conflicts which plague our coastal areas. The coastal zone is a combat zone. Spawning grounds are fast becoming sparring grounds. The menhaden and the mollusk pitch their freshwater demands against those of the power plant, the refinery, the irrigation canal, and the reservior. It doesn't take much to figure out who's winning the battle. If you need help--recall the snail darter and the Tellico Dam.

Consider the interests of Energy, Transportation, Commerce, and Agriculture--all represented at the Cabinet level. Then it becomes clear that the problems which beset the estuary are the problems which beset the Estuary Protection Act. The battle which rages in the coastal zone, rages as well on Capitol Hill. Transportation wants upwater ports. Energy wants hydroelectric power plants. Agriculture wants upstream diversion. Commerce wants coastal development. If there has been little consideration of estuarine needs amid all this construction, it is not for lack of law on the books. It is for lack of coordination. These competing agencies must be brought under a unified plan if development is to be balanced with preservation. But, no one yet has been appointed to do the balancing. So, development goes on upstream without regard to downstream, and now without regard to latter.

This call for national coordination and farsightedness harks back to the provisions of the Coastal Zone Management Act. CZMA could provide the necessary focus. However, CZMA is limited in its effectiveness for a number of reasons. First, the program is voluntary. Second, the requirements are procedural not substantive. The combination of these two factors tends to encourage states to take the money and run. Many of the participating states have succeeded in designating only one "area of particular concern." This kind of compliance is the means to no end.

States must be encouraged to view the national interest. Some may do so simply by looking to a neighboring state. One of the most pressing needs in the administration of CZMA is for improved coordination between or among two or more states which share a common watershed. Section 309 of CZMA added in 1976, amendments which provide for interstate grants to coordinate state coastal zone planning with respect to contiguous area--but it has never been funded. The problem of freshwater inflow cannot even be approached until there is provision for interstate planning. Fortunately, a few states are beginning to request that Section 306 administrative grants be made available for interstate planning. For example, Pacific Northwest states, through the medium of the Title II river basin commission, have requested interstate funds for the benefit of the Columbia River Estuary. The Great Lakes and New England River Basins Commissions have also been the recipients of Section 306 funding.

In reviewing the obstacles which OCZM faces in carrying out its mandate, I have mentioned the lack of coordination among states and the lack of coordination among Federal agencies. There remains a third obstacle which also should be obvious --the lack of coordination between the states and Federal agencies. Section 307 of the act is entitled, "Interagency Coordination and Cooperation." This section requires that Commerce coordinate its activities with other Federal agency activity. It also requires that each Federal agency operating within a state coastal zone be consistent to the maximum extent practicable with that state's coastal zone management program. As of this moment, these words have a hollow ring. Because there is little coordination of agency activity at the Federal level, it would seem to follow that there can be little or no coordination of that activity at the state level. These political realities make it difficult for OCZM to keep the goal of protection and wise use of the estuary at the forefront of its management program.

In addition, the provisions of the Coastal Zone Management Act, as they are now interpreted, cannot adequately treat the freshwater inflow problem. For instance, Section 315 of the act makes grant money available for the acquistion of estuarine sanctuaries. Florida is one state which has taken advantage of this provision to create an estuarine sanctuary at the mouth of the Apalachicola in the Gulf of Mexico. But this sanctuary protection does not extend upward into Alabama and Georgia to reach the freshwater tributaries which feed the river and the estuary. The sanctuary designation cannot or at least does not ensure proper quality, quantity, and timing of the freshwater inflow which originates beyond the sanctuary's reach.

The states of Florida, Georgia, and Alabama have agreed to pursue a Level B study to evaluate the water resources in the Apalachicola-Chattahoochee-Flint River Basin. In their FY 1982 study proposal to the Water Resources Council, the three states recognized that "all the uses and all the parts of the river system are interrelated." The states and the council believe that a Level B study can enhance the existing uses and values of the river system, while at the same time reducing the present conflicts over river system management.

Another factor which makes the act unresponsive to the freshwater inflow problem is one which could be corrected by a change in the administrative interpretation of a few choice words. The act provides that land and water uses governed by state coastal zone plans be only those which "have a direct and significant impact on the coastal waters." I think all of us here today would agree that freshwater inflow has a direct and significant impact on our coastal waters. Unfortunately, most of the states do not see it quite that way. In their evaluations of a sited project, they too often tend to look no further than the site itself. States must be encouraged to see beyound the site, beyound even state borders. But, if they are to do so, they need the impetus the Federal Government can provide; that means the money, and the authority to make interstate agreements. That means the Coastal Zone Management Act, as it may be amended this fall.

Up to this point, I have painted a rather gloomy picture. This was done in the spirit of realism. I would like to have been able to come before you and assure that freshwater inflow has been duly considered in every federally assisted development plan or project. It has not.

There are several actions the council could take to assure that estuaries and their freshwater needs are more adequately considered. First, the council could examine the adequacy of existing and proposed policies and programs and recommend to the President changes in Federal programs and policies which might be needed. We have this authority under the Water Resources Planning Act. Second, the council could also take more concrete steps to encourage the states, which are funded by our Title III grants, to regard estuarine needs in their water resources planning. The Title II river basin commissions, which are funded partly by the council, have already begun to move toward proper consideration of freshwater inflow and we can further encourage this.

These commissions are the ideal body to deal with the problems of interstate coordination in water resources plans. They have been created at the request of the states because those states recognize the inferiority of a development plan which does not look across state lines. As I mentioned earlier, three of these commissions have succeeded in getting CZMA funding in addition to our Title II funds. This is one example of successful coordination among Federal agencies whose objectives and responsbilities overlap.

The Council could give increased attention to freshwater inflow in its assessment activities, in its policy analysis, in its state grant program, and in its regional planning program. The council can also ensure that freshwater inflow will be adequately treated by the planners of Federal projects. Section 103 of the Water Resources Planning Act requires the council to establish principles, standards, and procedures for the formulation and evaluation of Federal water projects. At tomorrow's council meeting, the members will--I hope--approve the publication of the revised P&S as a final rule. The new P&S included the requirement to consider instream flows.

The procedures are contained in our manuals: for National Economic Development, for Environmental Quality, for Regional Economic Development, and for what has been termed Other Social Effects. The Environmental Quality manual, for instance, provides that planners comply with relevant provisions of the Coastal Zone Management Act. This necessarily broad mandate will not of itself ensure due consideration of freshwater inflow to estuaries. The manual cannot possibly set out all the elements of each of the thirty or so Federal laws for which it seeks compliance. However, the council plans to mention the peculiar freshwater inflow problem in its Reference Handbook which accompanies the various manuals going to the planners in the field. Luckily, the state-of-the-art is such that estuarine scientists can now predict the effects that irrigation projects, energy facilities, and harbor dredging will have on the delicate balance of the estuarine ecosystem. Scientists can now suggest thresholds for estuaries. These advances in technology will be reflected in the planning done in accordance with the Council's Principles and Standards.

Thus far, I have recounted how each of the council programs might respond to the newly perceived needs of the estuary. There is one further council program which had the potential to become a driving force in estuary protection. I am speaking of the Independent Project Review. In January 1979, President Carter signed an executive order which directs that the council perform an impartial technical review of preauthorization reports and preconstruction plans for Federal and federally-assisted water and related land resources projects. The Independent Project Review serves as a quality control mechanism. The order requires that all agencies submit cost-benefit information; evaluation of reasonable alternatives; evidence of compliance with environmental and other laws; and evidence of public, state, and local involvement in the planning process. A detailed finding of the areas of compliance or noncompliance will be returned to the agency head at the end of the 60-day review period. This information will also be transmitted to Office of Management and Budget (OMB) and to the Congress when the agency submits its project proposal to the Congress. It is important to note that the independent review is strictly a staff technical review. The findings do not go to the council members for review or approval but are transmitted by the chairman to the planning agency and are available to the public.

The independent project review will provide a checkpoint for seeing that the estuary and its freshwater inflow received proper consideration in the planning of Federal water resource projects.

To date, the project review unit is still engulfed in the continuing battle between the White House and certain factions of Congress over water policy in general and particularly over the omnibus water projects bill. Although we have statutory authority to perform the review, a rider on our 1980 appropriations bill prohibited the use of FY 1980 funds for the review until it was authorized after the date of the appropriations bill. The Senate Environment and Public Works Committee has reported out a bill authorizing the review but the House has not. We anticipate some action on this matter this month, but the situation right now is so uncertain that any prediction of future congressional action would be meaningless. Suffice it to say that the council believes the independent review is necessary to ensure that projects are well planned; we are confident we will get the review up and running; and we would welcome the opportunities that the independent project review would provide for the consideration of estuaries and freshwater needs.

So much for what the council may do with existing programs. I perceive that there could be a further role for the council in this arena. All of the interests which are finding themselves in pitched battle with one another in the coastal zone just happen to be members of the Water Resources Council. Actually, this is no coincidence. One purpose of Congress in creating the council was to coordinate all those agencies whose activities have some bearing on water and related land resources. The council can serve to mediate among the competing interests of Energy, Defense, Transportation, Agriculture, Housing and Urban Development, and the Environmental Protection Agency, but we can only do it successfully if those agencies want our help. For example, the council could offer the impetus needed to get the Estuary Protection Act to live up to its name. The Act needs recognition, funding, and the resolution of who is responsible for what between Interior and Commerce. The council could, in the next fiscal year, do the necessary analysis to determine how the act could be implemented in concert with agency reviews done under Section 404 of the Clean Water Act, NEPA, and other statutes to avoid duplication. This is the role that Congress envisioned for the council when it first conceived the idea of a coordinating, mediating body. To what better use could council efforts be put? Of course, with its small staff and other current initiatives, the council will need the support of its members to devote its resources to the freshwater inflow/estuary problem.

I have tried to set forth for you today the pattern of law and policy which surrounds agency decisionmaking at the Federal level. I have indicated the problems we have encountered in implementing that law and policy. I will now sum up some solutions to these probems which could be implemented at the national level.

The Nation must be made aware of the valuable resource that is the estuary. The Nation must also be made aware of the critical role that freshwater inflow plays in the maintenance of this valuable resource. One way to achieve this would be a directive such as an executive order from the executive office, similar to those employed to alert the country to the special needs of wetlands and floodplains.

The Estuary Protection Act could be seriously implemented. Undoubtly, OMB and the Congress would be more inclined to grant the necessary funding if the responsibilities of the various departments under the act became more clearly delinated.

The Coastal Zone Management Act could be strengthened. Because the program is voluntary, the states should have more incentive to participate. Mitigation funds under the Coastal Energy Impact Program are a part of that incentive. These funds for the mitigation of effects caused by the siting of energy facilities are only available to those states which develop a coastal zone management plan. Care must be taken that this funding is not abused, but that it remains available to cooperating states.

Regional or interstate planning must be encouraged. Within that scheme, some thought should be given to the funding of those states which are currently ineligible for CZM funds. The CZM Act must acknowledge in its eligiblity determinations that a state which has no coastal zone of its own may still be a major factor in the preservation of the estuarine system. Without the inclusion of these states, the act cannot pretend to consider the freshwater inflow needs of the coastal zone, and thus it cannot pretend to comprehensively consider the health and productivity of the estuary.

All of this, of course, is more easily said than done. But as we are often told, recognition of a problem is the better half of solving it.

I would like to see the Water Resources Council become part of the solution. And, that will take your help. The council provides a ready forum for discussion and solution of interagency coordination problems and of policy differences. I have the authority to propose the agenda for council action, and I have a small but competent staff to background the issues and propose the options. But, unless the members are disposed to act, unless they sense in their agencies some interest in a problem and some willingness to yield some portion of agency turf, very little will happen.

The council members are, in many cases, the secretaries of your departments. If you push, and we pull, our estuaries will be the winners.

ROLE OF THE NATIONAL MARINE FISHERIES SERVICE IN THE PROTECTION OF FRESHWATER INFLOW ESTUARIES

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Under the Fishery Conservation and Management Act of 1972 and other laws the National Marine Fisheries Service (NMFS) is assigned the management and conservation of the Nation's living marine resources, including those of a coastal, estuarine, anadromous, and offshore nature. NMFS regards preservation and enhancement of the productivity of these resources and the habitats upon which they depend to be an essential aspect of this responsibility.

The goal of this symposium is to review problems associated with freshwater inflow to estuaries and to formulate recommendations. Under this goal the purpose of my presentation is to emphasize the critical importance of freshwater inflows to marine commercial and recreational fisheries and to discuss some of the problems and experiences we have encountered in the protection of inflows.

Mineral and organic nutrients from freshwater inflows contribute to the particular richness of estuarine productivity. Inflow velocity, in combination with tidal forces, influences estuarine circulation, the recycling of nutrients, and, in some cases, the distribution of organisms. The net result of these and other factors is a national system of rich, and productive estuaries, which are important because of their unique aesthetic qualities and the valuable living marine resources which they support.

The importance of the estuarine environment to fisheries of the United States is considerable. Sixteen wetland species or species groups account for 57 to 63 percent or about three billion pounds of recent annual U.S. commercial fish landings. It is estimated that 60 to 70 percent of the most valuable commercial species of the Atlantic and gulf coast occupy estuaries during all or part of their life cycles.

Data compiled by the NMFS Recreational Fisheries Program indicate that in 1970 about 1.6 billion pounds of fish were caught by marine recreational fisherman. A 1975 study indicated that retail sales of about 2 billion dollars were attributable to marine recreational fishing. Since the majority of marine angling is for finfish, the importance of estuarine-dependent and related species to recreational fishing is apparent.

The basis for NMFS's resource protection activities stems principally from the Fish and Wildlife Coordination Act (FWCA) and the National Environmental Policy Act (NEPA). Protection responsibilities also derive from the Fishery Conservation and Management Act (FCMA), the Coastal Zone Management Act (CZMA), the Endangered Species Act, the Marine Mammal Protection Act, and the Columbia River Basin Fishery Development Program Act (Mitchell Act).

Due to the need to focus our existing program resources on problems of the highest priority, we are at this time beginning to place more emphasis on developmental impacts, which are related to or dependent on freshwater inflows. The San Francisco Bay and Delta, Columbia River, Chesapeake Bay, and the Gulf of Mexico coastal region have been identified as particularly important areas of concern. I am going to briefly address each of these four areas.

The urban-suburban area surrounding California's San Francisco Bay and Delta supports about 5 million people. With its strategic location and its huge natural harbor, the bay is a major center for commerce and industry. The estuarine system itself has historically provided abundant quantities of fish and shellfish. Of all our Nation's major estuaries which have had their freshwater inflows altered, San Francisco Bay and the Sacramento-San Joaquin Delta stand out among the others.

With population growth has come major changes to the estuarine system. Since the arrival of the gold seekers in the mid-19th century, intertidal wetlands have been reduced to about 17 percent of their former size. The result has been the loss of fish and wildlife habitats and a reduction of tidal-related flushing, which in turn has led to progressive deterioration of the quality of bay waters. In particular, increased trans-basin diversion of river inflow has limited the ability of the system to flush itself naturally. Currently, with inflows of only 5,000 cubic feet per second (cfs) from the Sacramento-San Joaquin Delta, one out of eight gallons of "freshwater" entering the bay is now sewage effluent.

The State of California estimates that the State's chinook salmon populations have been reduced 90 percent from their historic levels. Since the early 1960s spawning salmon in the Sacramento River system have declined more than 50 percent from the 1959-63 annual average of 420,000 fish. Striped bass populations in the San Francisco Bay estuary have also declined by between 60 percent to 80 percent. A major factor responsible for these reductions has been reduction in freshwater inflow to the estuary.

Two major diversions from the delta (the Central Valley Project and State Water Project pumping facilities) are used to export water to the south. The physical loss of fish caused by these diversions is substantial. Evidence collected by the California Department of Fish and Game indicates that the loss of young striped bass to diversions is a major factor threatening survival of this species in the estuary. It has been estimated that 31 percent of the striped bass and 25 percent of the young chinook salmon are passed through these pumping facilities and lost from the estuary. The actual diversion of striped bass is believed to be even greater because essentially all of the striped bass eggs and larvae approaching the pumps are passed through the diversion system into canals.

Continued or increased diversion of fish, fish eggs and fish larvae from the estuary will likely reduce the population's capability to be self-sustaining. If the export of fish from the system is allowed to continue, the once-important fisheries of San Francisco Bay and tributaries may be even more seriously impaired.

The inflow to the Columbia River estuary has also been altered. The most obvious impact to the fisheries, aside from the recent eruption of Mt. St. Helens, has occurred from habitat losses in upstream areas due to dams and reservoirs. Under the Mitchell Act, the NMFS has a long standing commitment to restoration and enhancement of Columbia River salmon and steelhead trout. These populations have been greatly impacted by mainstream hydroelectric development. As many of you know, up-river salmon stocks, which have been declining for many years, are now precariously few in number. Even with intensive management, Columbia River salmon and steelhead trout have also been substantially reduced from historic levels of abundance. As a result, careful study is now being given to various aspects of this problem, including freshwater inflow requirements in the river and estuary, in order to better manage the survival of young salmon during their downstream migration.

In Chesapeake Bay, as well as other east coast estuaries, stocks of striped bass have declined so dramatically that Congress has approved and authorized funding of special studies to determine the cause. Banning the commercial harvest of shad is being considered in Chesapeake Bay, since the catch has declined more than 80 percent since 1970 (i.e. from 5,150,000 to 994,000 pounds).

On an "average day" about 1 gallon out of every 30 gallons of freshwater inflow to the bay comes from sewage effluent. During the 1980's one of every two to three gallons of Chesapeake bay inflow will be warmed by electrical generators. Each time a bay area home is developed, approximately four tons of silt are added to the Chesapeake. Yet it is estimated that the land needed for residential purposes will approximately double between 1970 and 2020. Projected increases in manufacturing indicate that industry also will require 50 percent more land.

As populations and industries increase, more and more fresh water will be impounded and diverted to satisfy municipal and industrial needs. Unless political, social, and economic values are changed, the valuable natural resources of Chesapeake Bay may very well continue to dwindle and go the way of the Atlantic and short-nosed sturgeon.

The Gulf of Mexico estuarine area with its 207 estuaries is the largest in the United States, excepting those of Alaska. Through the early 20th Century, its fisheries did not assume major national importance. However, since 1940 things have changed. The gulf's predominantly estuarine-dependent fisheries now produce nearly 70 percent of all United States commercial fish and shellfish and over 30 percent of the dollar value. Yet development and agriculture are altering the vital comingling of fresh and salt water in Gulf estuaries.

The large estuaries of the Florida Everglades were once fed by millions of gallons of fresh water from the Kissimmee River-Lake Okeechobee and Big Cypress drainages. Over the last 80 to 90 years more than 1,500 miles of canals have been constructed to drain, divert, reroute and store this freshwater in "conservation areas". This has been done to replenish groundwater withdrawal by Miami and the populous Gold Coast. Freshwater depletion has intensified because of the prolonged lack of significant rainfall from hurricanes over the past decade. The result of this depletion has been a lowering of overall Everglades water levels by nearly six feet. Accompanying this has been a drastic reduction in characteristic marsh and mangrove communities, and disappearance of native soil due to oxidation and fire. Fisheries in the Ten Thousand Island area of Florida Bay are clearly experiencing decline. Hypersalinity is now common nearshore and once-abundant commercial and sport fisheries for redfish and sea trout have undergone substantial declines.

Apalachicola Bay in the northeast Gulf of Mexico is remarkably free of pollution and supports thriving oyster, shrimp, and crab fisheries. Proposals to dam the Apalachicola River at several locations have been staunchly opposed because of the potential degradation of and alteration to freshwater inflows. However, farms and rapidly growing cities annually pump hundreds of millions of gallons of water from the headwaters of the river. This water use may result in much more damaging long-term impacts to the estuary than would the proposed water projects. Oyster beds are now being lost from intrusion of oyster predators and parasites upstream in the bay. With additional freshwater diversion this problem could become a major affliction.

In the north-central gulf area, water-dependent agriculture poses a unique and substantial threat to thousands of acres of low-salinity marsh habitat. Rice growers in Vermilion Parish, Louisiana, concerned that saline water from Vermilion Bay will enter their fields, have proposed a series of permanent barriers to saline inflow. However, these barriers would cut off tidal exchange and segregate between 3,000 and 9,000 acres of low salinity marsh from the Vermilion Bay estuary. This important nursery habitat and area of productivity would be lost. Also lost would be millions of pounds of commercially and recreationally important white shrimp, blue crabs, menhaden and other estuarine-dependent fish and shellfish. Thousands of tons of plant detritus and dissolved organic matter, upon which Louisiana's estuarine food webs are based, would be lost from the estuarine system.

To wrap up, the maintenance of our Nation's estuaries is of vital concern because of their importance to living marine resources productivity, and maintenance requires inflows of suitable quality and quantity. Because of the NMFS responsibility for managing living marine resources, our impact assessment divisions and research elements have much to gain from these proceedings. We need additional research into freshwater inflow alterations and their impacts on the estuarine environment. We also need much more of the kind of information exchange which is occurring at this symposium. Finally, we need to assure that our information is adequately applied in the regulatory and development decisions which impact on freshwater inflows. Only through confronting these needs can we adequately address the problems which have brought us together today.

FRESHWATER INFLOWS AND FISH AND WILDLIFE SERVICE OPERATIONS

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The mission of the U.S. Fish and Wildlife Service (FWS) is to provide the Federal leadership to conserve, protect, and enhance fish and wildlife resources and their habitats for the benefit of people. Our authorities are derived from direct congressional mandates, such as the Fish and Wildlife Coordination Act, National Environmental Policy Act, the Endangered Species Act, as well as from executive and secretarial orders. I will comment on the major responsibilities of the FWS in the coastal zone and why we are concerned about freshwater inflow and the preservation of fish and wildlife habitats in estuaries.

The Service has several major responsibilities in the coastal zone:

> Under the Fish and Wildlife Coordination Act (FWCA) we are charged to evaluate the effects of all federally funded, licensed or permitted development projects on fish and wildlife resources and provide comments to the permitting or funding agencies. We review plans, recommend modifications or plans, and recommend mitigation measures when appropriate.
>
> We implement the provisions of the FWCA primarily through the Division of Ecological Services (ES). There are 25 ES Field Offices and Sub-Offices located on or near coastal areas that are directly involved in estuarine activities.
>
> Within the Division of Ecological Services, we have experts in marine biology and fisheries biology who evaluate works or activities that propose modification of estuarine systems, wetlands, and shorelands. As an integral part of their evaluation, they include all means and measures necessary to preserve the integrity of the ecosystem.
>
> We have direct regulatory responsibilities in administering the Endangered Species Act. There are over 40 federally-designated endangered species of birds, reptiles, mammals and fish in the coastal zone.
>
> The FWS has 115 national wildlife refuges on the coast that include over seven million acres.
>
> We participate in the Migratory Bird Treaty with Mexico and Canada which charges us with protection and management of all migratory birds including waterfowl.
>
> We have an active program to assist our Nation in planning and locating energy developments in the coastal zone. This work includes developing methods for assessing and predicting impacts, assembling information for use in impact

assessment and project planning, and conducting an ecological inventory of coastal resources.

We administer part of the Anadromous Fish Development Program and the Federal Aid to Fish and Wildlife Restoration Programs that provide funding for state conservation agencies. Many of these projects are in coastal areas.

We review and comment on coastal zone management plans developed by states under the Coastal Zone Management Act.

With stable budgets and personnel limitations to accomplish the work in these inflationary times, the FWS recently went through an evaluation to identify resource priorities. The FWS concern for the coastal zone of the United States came out clearly. As a result of this effort, we are shifting people and funds to address these problem areas. Of the 70 nationally Important Resource Problems in 1980, the highest five involved estuarine ecosystems and more than half involved coastal areas. These will be updated periodically to address new problems as they arise.

The most productive areas in the coastal zone for fish and wildlife are estuaries which depend upon freshwater inflow for their existence. We are deeply concerned when development projects on rivers reduce the volume of freshwater inflow, alter seasonal inflows, or change sediment or nutrient content. We are concerned when navigation and flood control projects prevent the natural distribution of fresh water and sediment into estuarine systems. The dumping of contaminants and sewage into estuaries through river pollution or through industrial and urban developments and non-point pollution from agriculture located directly on estuaries has magnified the deterioration of estuarine habitats.

The fact that our most productive coastal fish and wildlife habitats--estuaries--also attract people and industry intensifies our problem of protecting and preserving them. Many of our largest metropolitan areas--Boston, New York, Baltimore, Washington D.C., New Orleans, Houston, San Francisco, and Seattle--were located on estuaries because of their natural harbors and because they are attractive places to live near and develop.

I will concentrate my remarks on examples of some estuarine areas where critical freshwater inflow quality or quantity problems have developed. I will begin with the New York area and will discuss problems geographically around our coast to San Francisco Bay.

The Raritan Bay in the lower Hudson River estuary system is located in the New York metropolitan area. This system receives polluted freshwater inflow from the Raritan, Passaic and Hudson Rivers. This embayment is considered the most heavily polluted estuary in the Northeastern United States, and its problems were recognized over a century ago. By 1880, commercial harvesting of oysters and clams was prohibited because the shellfish were contaminated. This immense problem must be solved by reducing nutrient inputs, industrial wastes, and domestic sewage. Marsh restoration must also be emphasized. If Raritan Bay is ever to produce the food and recreation of the past, a massive cleanup program will be necessary. Even if influxes of pollutants were reduced, the residual levels of contamination in the sediments might be sufficient to affect the estuarine biota for several decades. Action programs to clean up these rivers have been resisted because of their costs. Although estuarine systems are capable of treating some organic wastes, they are not capable of handling unlimited volumes as the Raritan Bay case exhibits.

Chesapeake Bay is the largest estuary on the east coast and is surrounded by a population of about 8 million people. The principal stresses on the system are sedimentation, nutrient enrichment and influx of toxic substances. There have been widespread changes in the bay biota in recent years and the most critical are the loss of rooted aquatic vegetation and the decline in oyster production. Dredging of navigation channels, construction of harbor facilities, erosion of the shoreline and the watershed, accumulation of toxic materials and heavy metals in the sediments and biota have been primary problems.

The Environmental Protection Agency, U.S. Army Corps of Engineers, Fish and Wildlife Service, universities, states, and other groups are conducting studies on Chesapeake Bay and there is strong support for prudent baywide management decisions. The FWS is working actively to prevent further deterioration of this valuable ecosystem.

The State of Florida has serious freshwater inflow problems in Florida Bay and along the southwest coast. These problems began in 1882 when a small canal was constructed which diverted the southerly flowing water of the Kissimmee-Okeechobee-Everglades system into the Caloosahatchee River and then into the Gulf of Mexico. Substantial canal and water diversion efforts by private groups, the State of Florida, and the Federal Government have continued to redirect water that historically flowed southward through the Everglades into the south Florida estuaries. Most of the diversion has been for flood control, urban development and agriculture. The reduction of water flow through the Everglades and Big Cypress drainages into the estuaries has had the following consequences:

> The area of the south Florida Everglades has been reduced by 50 percent.
>
> Water levels in the Everglades have been reduced by 5 feet.
>
> The average period of overland flow in Everglades National Park has been reduced from 8 months to 4 months.
>
> Wading bird populations in freshwater wetlands have decreased from about 1.5 million in 1935 to 300,000 today.
>
> There has been a catastrophic reduction in nursery habitat for estuarine finfish and shellfish.
>
> Discharges of fresh water from canals into estuaries are often confined to short time periods and the sudden surges result in fish and shellfish mortalities in estuaries.
>
> Florida Bay has developed into a hypersaline area. It has essentially ceased to function as an estuary.

Solutions to these problems involve restoration of the natural sheet flow drainage and water storage capacity of the Everglades and Big Cypress systems. Without an appropriate timing and allocation of fresh water to the estuarine and coastal systems of Florida, the abundant resources which attracted many people to that State initially will be gone. This will not only affect Florida's coastal waters but the Gulf of Mexico fisheries as well.

Part of Apalachicola Bay has been established as a National Estuarine Sanctuary. Extensive studies in Apalachicola Bay and the Apalachicola River have identified the close relations among river watershed management, river inflow and estuarine production and species composition. The FWS is working with the State, local authorities, and other Federal agencies to prevent the estuarine degradation that has occurred in south Florida.

The Louisiana coastal region comprises the most productive estuarine system in the United States because of the large inflow from the Mississippi River and the vast wetland acreages it has created. Louisiana estuaries support about 20 percent of the wintering population of dabbling ducks in the continental U.S. and about 30 percent of the continental wintering population of diving ducks. Louisiana leads all states in the weight of commercial fishery landings and supported over 5 million days of sport fishing in 1975. The region has 148 colonies of nesting seabirds, shorebirds and wading birds. In 1976, these colonies included over 750,000 birds. These fish and wildlife resources depend upon wetlands for their existence and there is an annual loss of from 16.5 to 40 square miles of wetland in some parts of coastal Louisiana. Although natural causes have been responsible for some marsh subsidence and erosion, most of the losses have been attributed to man-caused actions.

These actions include construction of federally financed navigation channels, Mississippi River levees, flood control reservoirs, canal dredging and spoil disposal associated with oil and gas access, and drainage of wetlands for agriculture. Saltwater intrusion has changed much of the brackish and freshwater marsh to salt marsh. Although the total catch of oysters and shrimp has not decreased significantly, more effort is being expended to attain these catches.

> The catch per shrimp boat has decreased from 44,000 pounds in 1945 to less than 5,000 pounds in 1972.
>
> The production per acre of oysters has decreased from 500 pounds in 1945 to about 75 pounds in 1972.

The FWS introduced a plan to reintroduce fresh water into marshes in 1959. The Service also recommended that the Mississippi River and Tributaries Act of 1928 be amended to include diverting river flow into these estuarine habitats. The act was amended in 1965 but no major federally funded measures have been constructed. The FWS through the Division of Ecological Services, is assisting the Corps of Engineers in developing this program. The FWS calculated that one structure alone would result in annual benefits of between $4.4 million and $5.2 million.

The Atchafalaya River embayment is the only major area in Louisiana where a delta is developing on the

Louisiana coast. We are working with the Corps of Engineers to maximize delta development in Atchafalaya Bay when navigation maintenance and development work is required. We have excellent opportunities to reintroduce fresh water into several marshes with this effort.

I want to commend the Louisiana Legislature for directing the Louisiana Department of Transportation and Development to prepare a freshwater reintroduction plan. With both State and Federal efforts, we are optimistic that we can retard the loss and develop more Louisiana marsh habitat.

The restoration of Louisiana wetlands will be of significant value for hurricane protection, pollution control, nutrient cycling, and flood control. Many of the measures we are recommending to benefit fish and wildlife have benefits to people as well, but they have not been adequately quantified.

The freshwater inflow to estuaries issue is more complex along the Texas coast of the Gulf of Mexico than in Louisiana for several reasons:

> Many rivers are involved in Texas while in Louisiana most of the freshwater flows to estuaries comes from the Mississippi River and its distributaries.
>
> The Texas coast rainfall ranges from semi-arid levels in the Brownsville and Corpus Christi area to relatively high levels around Galveston and Houston. Great natural differences in rainfall occur between wet or hurricane years and dry or arid years.
>
> The competition for the use of water is intense in Texas because of irrigation development, population and industrial growth. Much of the industrial growth is concerned with energy production, one of our Nation's primary problems. Water availability is a primary deterrent to increase agricultural and industrial growth in Texas.

The State of Texas has been dealing with the freshwater inflow to estuary problems effecttively from the standpoint of data collection and the development of predictive models. The freshwater needs of six estuarine areas have been quantitatively described in a study conducted by the Texas Water Resources Department that has been submitted to the Texas Legislature. Therefore, the people of Texas recognize the need for providing freshwater inflow to sustain estuarine ecosystems if they expect estuaries to produce shrimp, oysters, fish, or waterfowl in the future.

The FWS has several programs along the Texas coast that involve freshwater inflow to estuaries:

> The FWS considers the Texas coast to be one of the highest priority areas in the U.S. when it comes to preserving habitat for endangered species and for wintering migratory waterfowl and other birds. The coastal national wildlife refuges furnish part of these habitat needs but we intend to use all our resources to protect additional habitat through identifying and providing information on freshwater inflow needs and habitat values, and by making sound scientific recommendations in our Coordination Act reports.

We have conducted freshwater inflow and field studies in the Nueces-Corpus Christi estuaries and have an ongoing freshwater inflow study in the Matagorda Bay system. These studies, costing over $1.2 million, will assist us in providing technically sound recommendations on freshwater inflow needs of selected estuaries. We believe that the best possible technical information and methods should be made available to state and Federal agencies and to persons responsible for making decisions on freshwater inflow.

We are particularly concerned with the effects of industrial development and water use in rivers that flow into the Galveston Bay ecosystem. If we can conserve a significant part of the fish and wildlife habitat in the biologically productive Galveston Bay ecosystem, we will have accomplished much. We believe that a comprehensive water management plan that considers industrial, urban, agricultural, and fish and wildlife needs should be prepared for this heavily populated growing area. If such a plan is properly prepared and accepted by State, Federal, and local governments, it would assist everyone in carrying out their responsibilities for preserving this important estuarine habitat. More important, it would make the Houston-Galveston area a more attractive place to live in and enjoy.

The Service is going to continue to exercise all measures within its power to ensure that adequate fresh water is provided to sustain the estuarine ecosystems on the Texas coast.

Probably no estuary in the United States has been changed more by man than the San Francisco Bay. The ecosystem extends from San Francisco Bay to the Sacramento-San Joaquin Delta. The degradation process in the area started with hydraulic gold mining in the 1800's. Next, tidelands were filled for urban and industrial development. Pollution from the growing population and from industry intensified the problem. Finally, increases in agriculture and urban development led to massive water diversion. The bay ecosystem was impacted by a combination of reduced volume of freshwater inflow, filling in of the bay, and reduced water quality. The bay ecosystem provides recreational, scenic and aesthetic benefits to over 5 million urban and suburban residents. The inflow into the bay is now only half of the natural amount and it is expected that the inflow will decrease by another 50 percent by the year 2000.

Fish and wildlife resources and habitats have decreased significantly:

> In the San Joaquin River the entire spring chinook salmon run has been lost and the fall run is only 10 percent of its historical size. The chinook salmon run in the Sacramento River is about 40 percent of its size in 1953.
>
> Between 1960 and 1979, the striped bass population has decreased by over 50 percent. Water diversion and saltwater intrusion are the assumed causes of this decline.

> Approximately 95 percent of the original 850 square miles of natural tidal marshes in the bay complex have been filled or lost. The remaining tidal marshes--about 43 square miles --contribute over 11 thousand tons of carbon annually to the San Francisco Bay estuary.

> Suisan Marsh furnishes about 25 percent of the wintering habitat for waterfowl in the Pacific Flyway and we have lost over 80 percent of the area of this marsh alone.

Water diversions for agriculture, urban and industrial needs by Federal and State agencies and by private developers have been the main causes for these fish and wildlife resource losses. What has the FWS been doing to prevent further deterioration of this ecosystem? We have been handling our Coordination Act activities since the 1950's, but until recently our effectiveness has not been good. We have received support from private conservation groups, the State of California and other Federal agencies. The California State Water Board provided a Water Right to protect striped bass and Suisun Marsh in 1978. Presently a four-agency group--California Department of Fish and Game, California Department of Water Resources, U.S. Water and Power Resources Service, and the Division of Ecological Services in the U.S. Fish and Wildlife Service--is attempting to work out satisfactory solutions to protect the remaining habitat. We would like to have a comprehensive water plan developed that would include fish and wildlife water needs along with agricultural and urban needs. We are developing better data and methods for predicting impacts. We need to We need to conserve and enhance the remaining fish and wildlife habitats in the San Francisco Bay ecosystem. Heavy public involvement is essential and we are optimistic that progress is being made.

An outstanding example of our progress is the Secretary of the Interior's support of instream flows for the Central Valley Project for the improvement of the delta marshes and San Francisco Bay ecosystem. A departmental draft EIS is currently undergoing public review that proposes legislation to reauthorize the Central Valley Project to save delta water quality and fish and wildlife needs on a permanent basis.

Freshwater inflow problems have also been identified in several other estuaries along the Atlantic coast, in the Gulf of Mexico, Southern California, in the Pacific Northwest, and in Alaska. Particularly in Alaska, we have the opportunity to bring the freshwater needs of estuaries into the early stages of planning. Even though water allocation has not become a front line issue on the Atlantic coast, the issue will have to be addressed within the next 10 years.

There are certain general observations that I would like to emphasize in concluding my remarks. First, many of the measures we are recommending to benefit coastal fish and wildlife resources will serve other functions as well, such as hurricane protection, water purification, contaminant removal, and flood protection. Although direct economic benefits to man have not been quantified, they are real. As an example, it is cheaper and less energy intensive for natural processes to clean water than to use expensive waste water treatment systems.

Second, while there is a short-term ebb and flow, there is a strong trend in the Congress and from private and governmental groups living around our major estuaries that favors a stronger environmental ethic and that state, Federal and local governmental groups are working together more so than in the past. Public pressure is demanding this action and we hope it continues.

Third, we need to develop comprehensive planning procedures that will force us to consider the water needs of our natural ecosystems along with domestic, agricultural, and industrial water needs. We cannot address the problem of cumulative impacts effectively without comprehensive planning. Although land and water planning appears to be anathema to the American way of doing things, we cannot protect important ecosystems in our estuaries without it. Comprehensive planning requires the integration of inland river and coastal planning.

Fourth, we need to improve our capability to predict the effects of various amounts and qualities of freshwater inflow on estuarine ecosystems.

Finally, the Fish and Wildlife Service is going to take every measure possible to preserve, protect and expand the estuarine habitat of our Nation. I am sure that this symposium will develop some innovative and practical ideas to assist us.

FRESHWATER INPUTS AND ESTUARINE PRODUCTIVITY

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ABSTRACT

The processes responsible for the high level of production characteristic of estuarine systems are not yet well understood. There are at least five major hypotheses which have been put forward at various times to account for estuarine production, including the fertilizing effect of nutrients in fresh water, advection of nutrient rich offshore water, the trapping of nutrients in estuarine circulation, the outwelling of nutrients from salt marshes and other wetlands, and the rapid recycling of nutrients within the estuary. The remarkable similarity of primary and (to a lesser degree) secondary production levels among estuaries with widely varying fresh water inputs, hydrodynamics properties, and geographical and geological characteristics suggests that a more general feature of estuarine systems is most important in enhancing production in these areas. While river inputs may contribute to the spring bloom, most of the production in many estuaries appears to take place during the warmer months and to be supported by recycled nutrients. Two characteristic features of estuarine systems are their shallow depth and relatively strong mixing. Both of these features contribute to a relatively complete and rapid coupling of heterotrophic and autotrophic processes in estuaries. Because remineralization appears to be a slower process than the formation of new organic matter, it may be that heterotrophic processes play an important role in regulating the primary production of estuaries, and that the similarity of carbon fixation rates in various estuaries arises because of some common limit on the rate of nutrient recycling. More attention also needs to be given to the problem of understanding the relationship between short-term processes, such as annual production or regeneration, and longer-term processes, such as the continuous input of nutrients from rivers and anthropogenic sources.

THE NATURE OF THE PROBLEM - WHY ARE ESTUARIES SO PRODUCTIVE?

Estuarine systems are usually characterized by levels of primary production per unit which are considerably higher than those typical of offshore waters (Table 1). In many cases, the higher production of estuarine and nearshore waters has been attributed either directly or by implication to the fertilizing effect of river inputs of nitrogen, phosphorus, or silica.

> The river appears to be the
> principal source of nitrogen
> and phosphorus in the estuary
> (Forge River, Moriches Bay,
> L.I.), (Barlow et al. 1963).

Table 1. Estimates of annual primary production in estuarine, nearshore, and offshore waters along the U.S. east and gulf coasts.

Area	Production ($g\ C/m^2/yr$)
New York-New Jersey[a]	
Lower Hudson Estuary	820 (690-925)
Mouth of the Estuary	640
N.Y. Bight Nearshore (<8 km)	420
N.Y. Bight Apex	370
Continential Shelf (<50 m deep)	160
Continental shelf (100-200 m deep)	135
Edge of shelf (>1000 m deep)	100
Georgia[b]	
Inshore behind barrier islands	300
Continental Shelf (<20 m deep)	285
Continental shelf (20-200 m deep)	130
Louisiana[c]	
Barataria Bay	360
Nearshore shelf	265
Gulf of Mexico	35

[a] Ryther and Yentsch 1958; Mandelli et al. 1970; Malone 1976; O'Reilly et al. 1976; Thomas et al. 1976a, 1976b.

[b] Haines 1979

[c] El-Sayed et al. 1972; Day et al. 1973; (macrophytes and phytoplankton); Sklar 1976

> The distribution of nitrate in the upper Chesapeake Bay.. ..suggests that the inflow of the Susquehanna River... is the major source...(Carpenter et al. 1969).
>
> The high fishery productivity of the water adjacent the river mouth is a result of nutrient contribution by the Mississippi River...(Ho and Barnett 1977).
>
> River inflow is clearly a major source of substances to the estuary (San Francisco Bay)...(Peterson 1979).

Conclusions such as these seem intuitively correct because the concentrations of nutrients, particularly inorganic nitrogen and silica, are usually much higher in fresh water than they are in coastal sea water (Figure 1). But the situation is more interesting than it first appears, and even this simple relationship may be reversed. For example, in their studies of one of the world's major rivers, Ryther et.al. (1967) found that:

> In the surface water influenced by the Amazon River compared with the surrounding seawater, the concentrations of nitrate, phosphate, and planktonic organisms were lower while the levels of silicate were appreciably higher. The direct over all effort of the river, therefore, is to decrease the fertility of the ocean into which it flows.

While the behavior of the Amazon may be a remarkable exception, it still does not necessarily follow that the higher concentrations of nutrients normally found in rivers will make freshwater inputs a major factor in estuarine nutrient dynamics. And it will require considerably more than a description of the freshwater-saltwater nutrient concentration gradient to properly assess the role of fresh water in enhancing the productivity of estuaries.

I think it is important to realize how confused we still are about this fundamental problem of estuarine (and nearshore) productivity, and how far we still are from a full understanding of coastal marine nutrient dynamics. If we keep our sense of humor and some perspective on the real complexity and challenge of the problem, it can be humbling and amusing to watch ecologists arguing that salt marshes are valuable because they "outwell" nutrients (which supposedly make the estuary productive) and because they provide "tertiary treatment" which removes nutrients from the estuary which supposedly are making it eutrophic (Nixon 1980). In a symposium focusing on the importance of freshwater inputs, the tendency is to emphasize the role of rivers in bringing "good" nutrients into the estuary. But in another context the emphasis is likely to be on the harmful effects of "bad" nutrients from sewage or agricultural runoff.

FRESHWATER INPUTS AND OTHER HYPOTHESES

Given the present state of knowledge, it should not be surprising that a number of alternative hypotheses have been developed which attempt

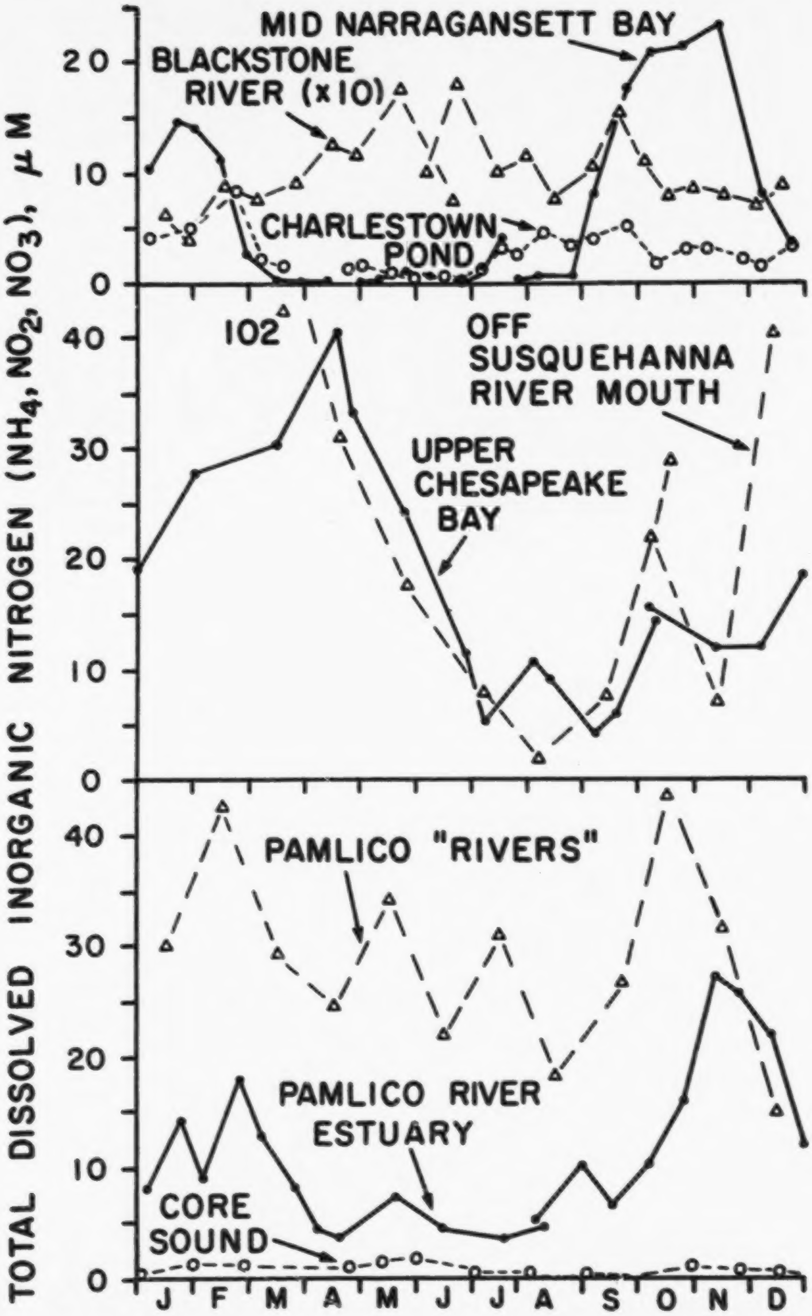

Figure 1. Dissolved inorganic nitrogen concentrations over an annual cycle in the fresh, estuarine, and inshore marine waters of three estuarine systems on the Atlantic coast of the United States. Data from Nixon (unpublished) and Nixon and Lee (in press)for Narragansett Bay; from Whaley et al. (1966) for Chesapeake Bay; and from Harrison and Hobbie (1974) and Thayer (1974) for the Pamlico River and Sound.

to account for high estuarine productivity without calling for a fertilization of the estuary by river inputs. In general, there are four major themes other than freshwater input which appear in the literature, and I think the quotes given below will give a good feel for the diversity of opinion they represent.

1. Fertilization by advection of deeper offshore waters

> General conclusions are that the usual pattern of exchange between inshore and offshore waters tends to enrich the coastal zone irrespective of enrichment by freshwater drainage...(Riley 1967).

2. Fertilization by marshes

> Apparently, large rivers do not have as great a local effect on the productivity of estuaries and coastal waters as was once assumed. I think the most important discovery we have made in our 15 years study of production dynamics on the Georgia coast is that the high fertility of this region is self-produced within the salt-marsh estuary, and is not due to nutrients washed down the rivers (Odum 1968).

3. Fertilization by concentration - the nutrient trap

> In estuaries fresh water derived from the land...mixes with sea water and is carried seaward in the upper layer of the embayment. A counter-current of sea water moves in from the outer sea to replace that entrained in the surface outflow...consequently, the redistribution of nonconservative elements by the sinking of organized matter will tend to cause the concentration of N to increase upstream relative to the motion of the surface layer. The estuarine circulation creates a trap in which nutrients tend to accumulate. (Redfield et al 1963).

4. Fertilization by rapid recycling

> ...For the Georgia and South Carolina shelf, nutrient influx to the coastal zone via outwelling is of minor importance, mixing of deep water across the edge of the shelf is of minor importance, and in situ regeneration is the most important process in maintaining high rates of nutrient flux and hence high rates of biological productivity in the shelf waters. (Haines 1975).

Each of these mechanisms deserves a serious consideration that is beyond the scope of this paper. But as a start, the various possibilities can be brought together in a conceptual model (Figure 2), and we can begin to focus on fresh water input as one of at least five alternative explanations for estuarine production. It may be, of course, that different explanations apply to different estuaries or that estuarine productivity is a consequence of all of these things happening together, a conclusion reached by Correll (1978) in his recent consideration of the problem:

> Thus, estuaries maintain high production by maintaining high nutrient levels in bottom sediments and water column. This is done by nutrient/plankton trapping via the "salt wedge"

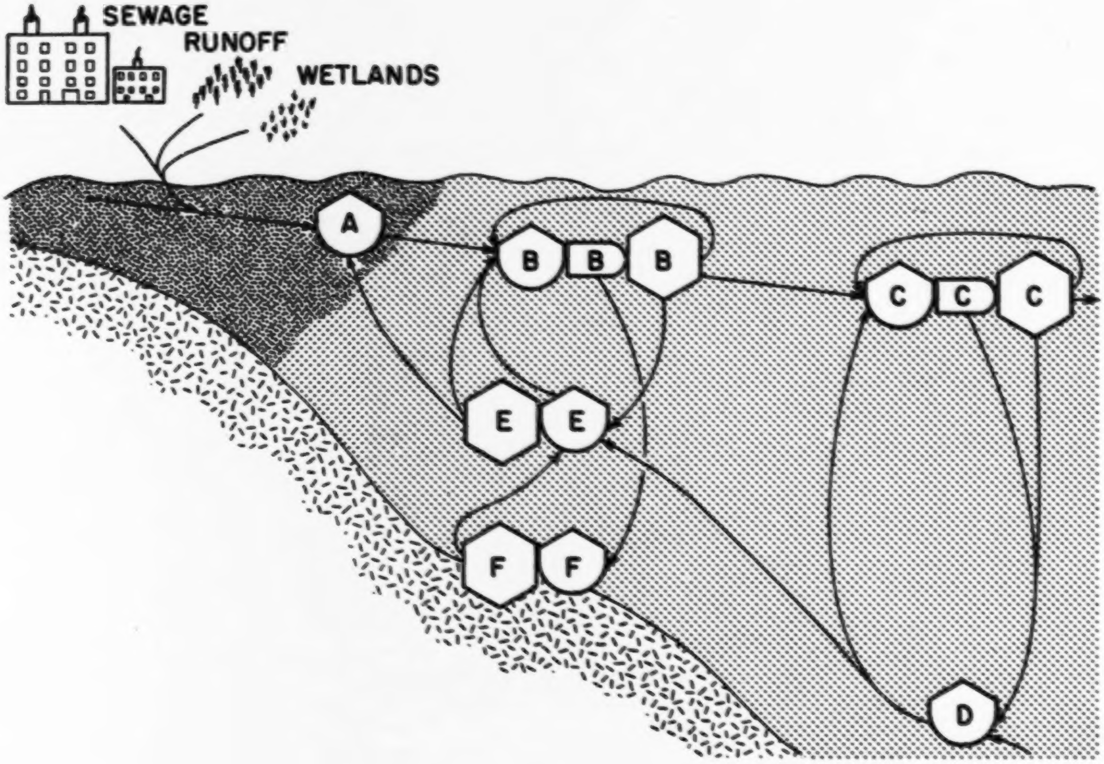

Figure 2. Conceptual model illustrating five common hypotheses concerning the factors responsible for bringing about high levels of estuarine primary production: 1) The estuarine nutrient pool (B) is simply fertilized by freshwater input (A) which may or may not include anthropogenic inputs; 2) Nutrient-rich deep water from offshore (D) is brought into the estuary (E) by the estuarine circulation pattern where it is rapidly mixed up into the euphotic zone (B) by strong tidal and wind effects; 3) The estuarine nutrient pool is fertilized by inputs to rivers (A) and the estuarine tidal waters (B) by outwelling of nutrients from fresh and salt marshes and other wetlands; 4) Nutrients in the estuary (B) are taken up by the estuatine plankton (B) which fall to the deeper water (E) and are carried back upstream by the landward flowing bottom water where they are entrained in the seaward flowing fresher surface water (A) and can be taken up once again by the estuarine plankton (B) and; 5) Inputs to (B) from (A) and (D) are much less important than the recycling of nutrients within the system (B,E,F).

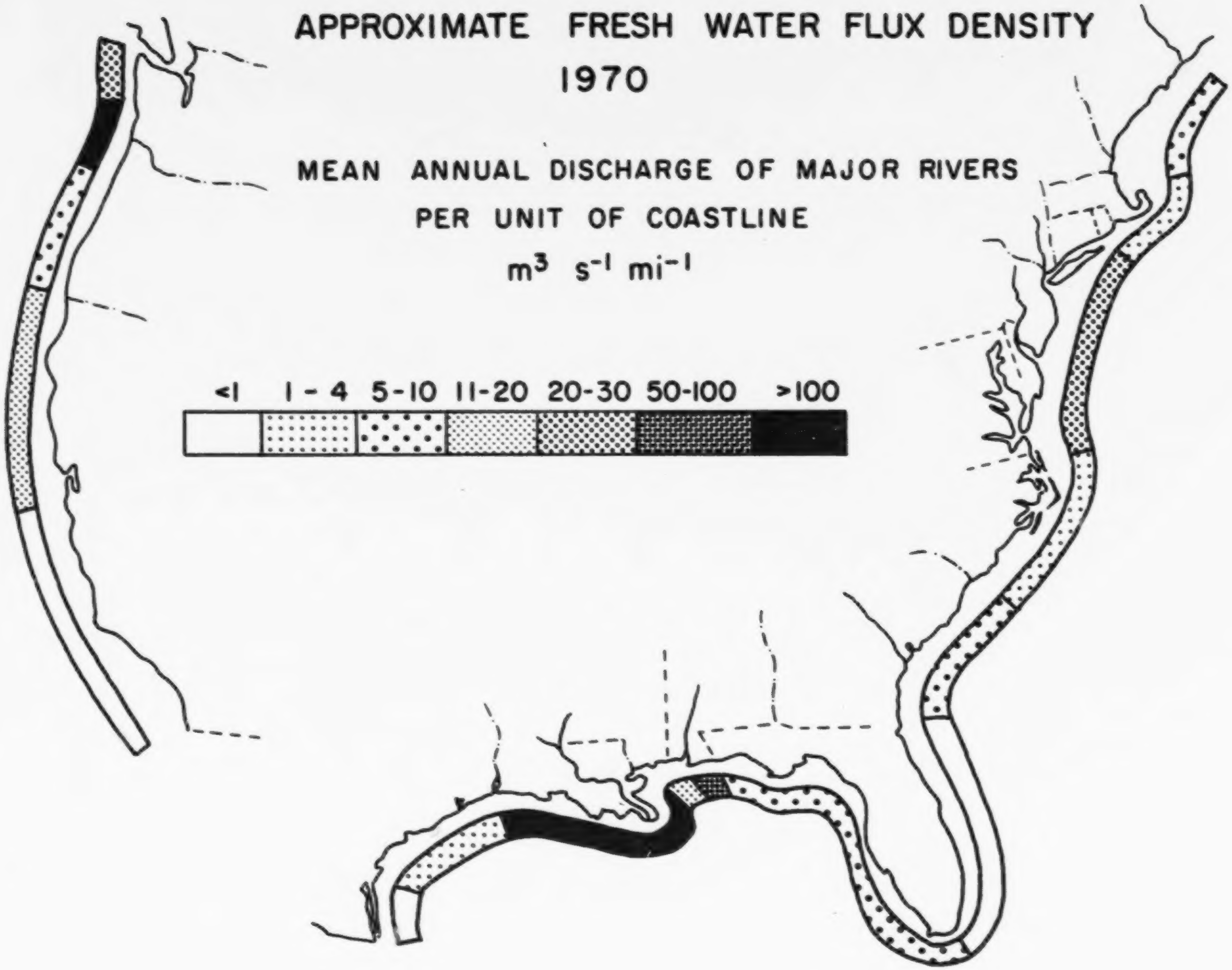
APPROXIMATE FRESH WATER FLUX DENSITY
1970
MEAN ANNUAL DISCHARGE OF MAJOR RIVERS
PER UNIT OF COASTLINE
$m^3 s^{-1} mi^{-1}$
<1
1 - 4
5-10
11-20
20-30
50-100
>100

Figure 3. A rough approximation of the flux of fresh water from major rivers along the coast of the coterminous United States (UNESCO 1974).

countercurrent and the nutrient modulating actions of tidal marshes, bottom sediments, and submerged vascular plants.

It is difficult to argue with the proposition that estuaries are highly productive because of all the things that make them estuaries, but it would be nice to know a bit more about the relative importance of the different features of estuaries in this regard. Similarly, it may finally be true that each estuary represents a unique set of processes coming together in a special way to result in a particular level of production. But before having to treat each estuary separately, I think the most useful course to begin with is to press hard for a general model or concept. If various unified views can be stated, and shown to fail, then we can always fall back on the diversity and uniqueness of nature for an explanation.

SOME OBSERVATIONS ABOUT FRESHWATER INPUT

There are at least three characteristics of river input that are of interest in trying to assess the importance of this feature in general estuarine productivity, including the magnitude of water flow, the concentration of nutrients in the water, and the seasonal variation of each.

THE MAGNITUDE OF FLOW

It is clear that the amount of fresh water being discharged along the coast is extremely variable (Figure 3). The influence of this discharge on the salinity of the estuarine receiving waters, however, is more complicated, because that parameter also reflects the volume of the estuary, the tidal prism, and the mixing and flushing characteristics of the system. In general, however, all of these features seem to combine with freshwater inputs to produce estuaries with lower mean salinities along the southeast and gulf coasts of the United States (Figure 4). It is very difficult to know if this apparent trend is real or if it arises simply because of the location of sampling stations on the various estuaries. If it is real, it would seem reasonable to expect that the influence of fresh water might be greater in these estuaries and that they might therefore be quite different from more northern systems in their productivity if freshwater input is important in this regard.

NUTRIENT CONCENTRATIONS

As far as I am aware, there are remarkably few reliable measurements of the major nutrients in rivers flowing into estuaries and even fewer which include a total inventory of all of the major forms of the nutrients over an annual cycle. While documents summarizing the ionic composition of many substances of geochemical interest are available (e.g. Livingston 1962), the apparent variability and scarcity of data on nutrient chemistry seem to have effectively prevented anyone from putting together a credible geographical summary. The problem is further complicated by the development of agriculture or the location of large urban areas along the lower reaches of many rivers, so that the anthropogenic contribution to the riverine nutrient load can be very large and extremely variable from estuary to estuary. The resulting expectation

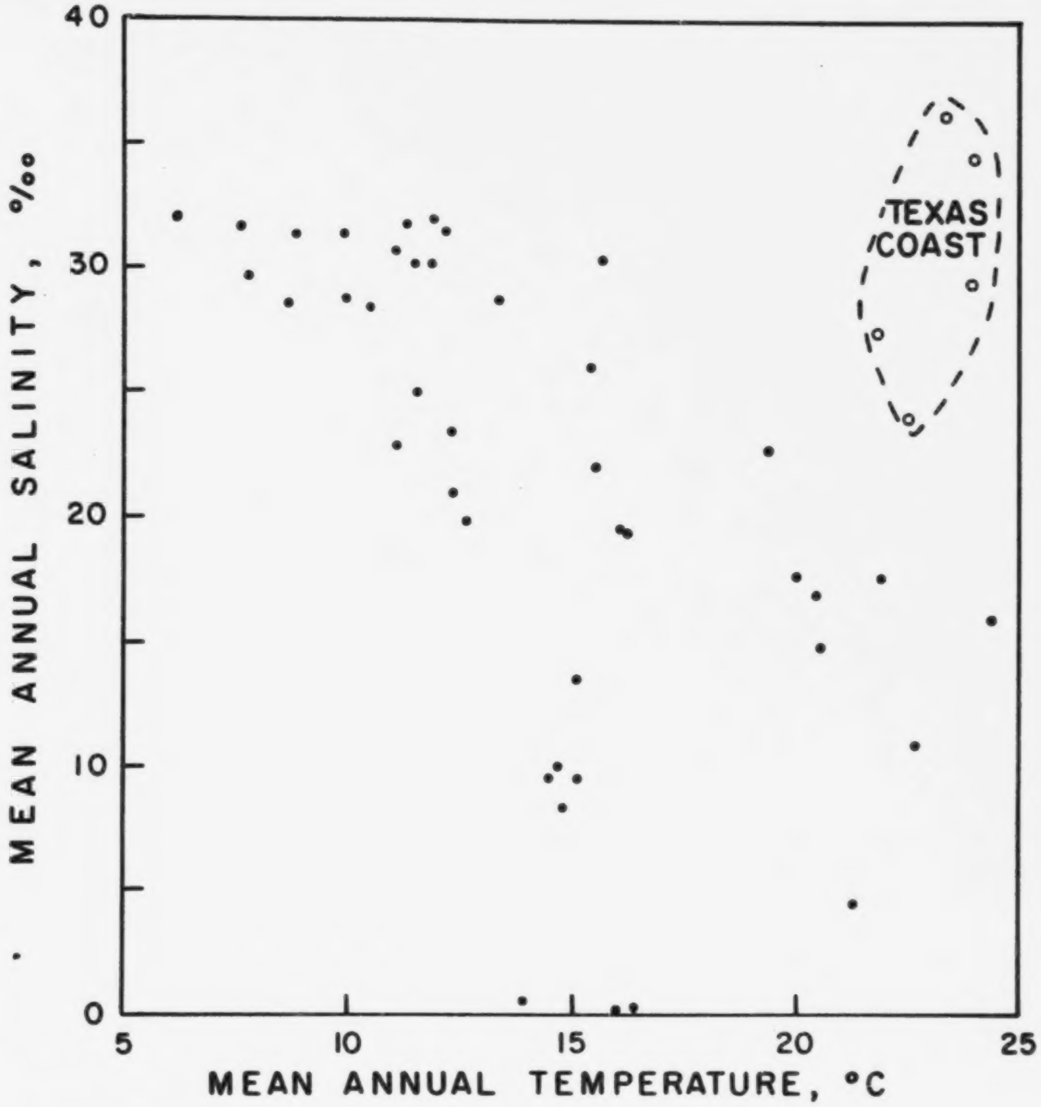

Figure 4. Mean annual surface water salinity and temperature at 46 estuarine and nearshore sampling stations reported by the U.S. Department of Commerce (1960). The length of record varies.

(though based on little evidence) is that the amount of N, P, or Si being delivered to various estuaries ought to vary considerably (Jaworski, in press), and that if this feature is important in regulating primary production, it might also be expected to vary widely.

SEASONAL VARIATION

The inflow of freshwater varies seasonally to a greater or lesser degree in different estuaries as a function of rainfall, temperature, and watershed size and characteristics. In many (perhaps all) estuaries, a higher rate of freshwater input is associated with a higher rate of nutrient input as well, but because there is often some dilution of concentration during periods of higher discharge, the total flux of nutrients may be more constant during the year than a simple inspection of the yearly discharge cycle may suggest. Overall, however, periods of high discharge will bring about an accumulation of fresh (presumably high nutrient) water in the estuary and result in a lowering of the salinity. The annual variation in salinity differs considerably among estuaries for all of the reasons mentioned previously, but an excursion of 5 to 10 percent is not uncommon (Figure 5). If river input is important in driving the primary production of the estuary, we might expect to see some enhanced production associated with this period of increased discharge and/or lowered salinity.

SOME OBSERVATIONS ABOUT

ESTUARINE PRODUCTION

REGIONAL VARIATION - A COMPARISON OF SYSTEMS

Primary Production

In reviewing the various studies of primary production in estuarine systems, I have been impressed by the remarkable similarity of virtually all of the annual estimates (Table 2). With few exceptions (such as the highly eutrophic lower Hudson River), there appears to be somewhere between 150-400 $gC/m^2/yr$ fixed in shallow coastal waters when an average is made over a whole estuarine system. Values higher than these are certainly found in seagrass and seaweed beds, but when their production is apportioned over the whole estuary and added to the lower area-based phytoplankton production that is usually found in such shallow waters, the total production seems to fall in with that found in deeper plankton-based systems. The same may be true of estuaries with very productive intertidal or shallow subtidal benthic diatom communities, though there are too few measurements of this component to generalize with any confidence. It seems to me that this small variation in production (approximately a factor of 2-3) compared with the very large range in estuarine freshwater input (orders of magnitude) suggests that it is some other, more constant

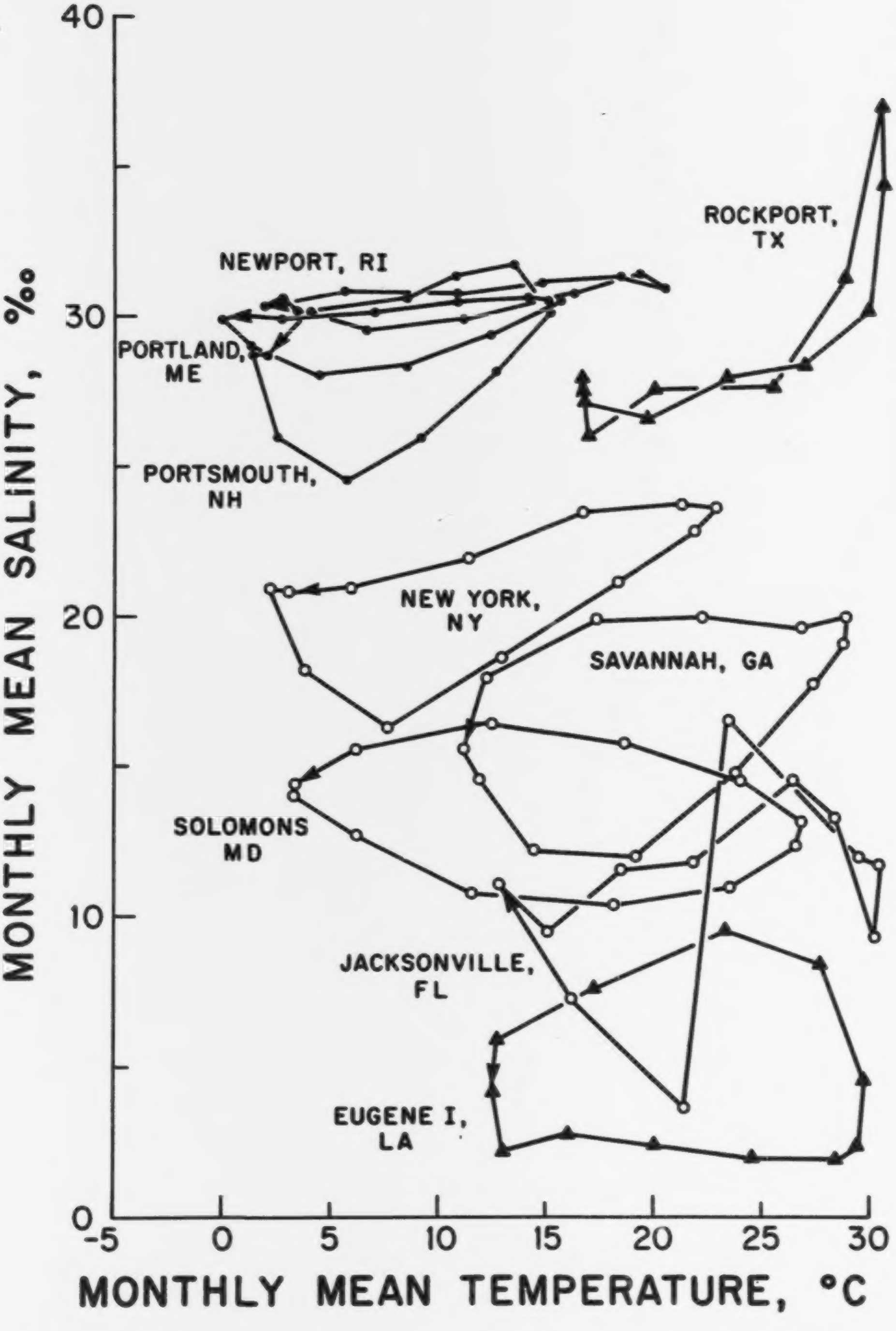

Figure 5. Variation in mean monthly salinity and temperature in the surface waters at nine estuarine sampling stations along the Atlantic and gulf coasts of the United States (U.S. Department of Commerce 1960) Length of record varies.

Table 2. Estimates of particulate primary production in some U.S. and Canadian estuarine and nearshore waters.[a]

Area	Primary Production ($g\ C/m^2/yr$)
Bedford Basin, N.S. (Platt 1975)	220
St. Margaret's Bay, N.S. (Platt 1971; Mann 1972 a,b)	790[b]
Narragansett Bay, R.I. (Furnas et al. 1976)	310
Charlestown Pond, R.I. (Nixon and Lee, in press)	140[b]
Block Island Sound, R.I. (Riley 1952)	285
Long Island Sound, (Riley 1956)	205
Hempstead Bay, L.I. (Udell et al. 1969)	215[b]
Peconic Bay, L.I. (Bruno et al. 1980)	190
Lower Hudson Estuary, N.Y. (O'Reilly et al. 1976)	690-925
New York Bight Apex (Malone 1976)	370
Patuxent River, M.D. (Stross & Stottlemeyer 1965)	210
Chincoteague Bay, M.D./V.A. (Boynton 1974)	180
Pamlico River Estuary, N.C. (Kuenzler et al. 1979)	200-500
Inshore Sounds, N.C. (Dillion 1971; Thayer 1971)	345[b]
North Inlet, S.C. (Sellner et al. 1976)	260
Salt Marsh Creek, G.A. (Turner et al. 1979)	90
Inshore Sounds, G.A. (Haines 1979a.)	300
Off Altamaha River, G.A. (Thomas 1966)	550
Nearshore Shelf, G.A. (Haines 1979a.)	285
Barataria Bay, L.A. (Day et al. 1973)	360[b]
Nearshore Louisiana (Sklar 1976)	265
Columbia River Mouth (Anderson 1964)	80
Puget Sound, W.A. (Winter et al. 1975)	465
Burrad Inlet, B.C. (Stockner and Cliff 1979)	350
Kaneohe Bay, H.I. (Smith 1981)	165

[a] Phytoplankton only unless otherwise noted

[b] St. Margaret's Bay phytoplankton = 190; seaweeds = 600
Charlestown Pond phytoplankton = 30; benthic plants (not included seaweed) = 110
Hempstead Bay phytoplankton = 198; benthic plants = 17
North Carolina sounds phytoplankton = 70; benthic plants = 275
Barataria Bay phytoplankton = 165; benthic plants = 195

feature of estuarine systems that makes them so productive. The same could be said of the importance in this regard of salt marshes or estuarine circulation patterns, both of which are features which vary widely among estuaries (Nixon 1980; Kjerfve et al. 1978).

Secondary Production

It is reasonable to ask if the similarity of estuarine primary production is reflected in a relatively small range in secondary production. Unfortunately, the great difficulty of obtaining measurements of the rate of production of higher trophic levels has made it impractical to answer this question directly. The best we may be able to do is to estimate the relative production of animal biomass in estuaries through the use of fishery yields. It is always risky to use landings data because of sampling problems and a number of other difficulties. Nevertheless, these data represent the best comparative information available and, after reviewing the fisheries yield data for a large number of lakes, Ryder (1965) concluded "that catch is a reliable estimate of fish production despite the variables affecting it." As far as I am aware, however, it is not known how good fish production is as an indicator of total secondary production.

There are at least two ways to address the problem. First, the yield of a given estuary can be compared with its freshwater input as they vary from year-to-year and, second, the yields of various estuaries with different levels of freshwater input can be compared. In looking at variations over time in the Gulf of St. Lawrence region, Sutcliffe (1972, 1973) was able to find a strong positive correlation between river discharge and the catch (after appropriate time lags) of various species. A similar positive relationship was reported by Turner (1979) for oyster landings in Mobile Bay, Alabama. However, an analysis of five years of total commerical landings data from five estuaries on the Texas coast provided more ambiguous results which Armstrong (1980) interpreted as showing a curvilinear relationship with an optimum rate of freshwater input. In the case of shrimp, on the other hand, it appears that there is a strong negative linear correlation between freshwater input and production if one compares the mean annual salinity of Lake Pontchartrain with the Louisiana landings (Turner 1979). A similar relationship appears to be evident, particularly over the past 30 years, between Mississippi River discharge and Louisiana shrimp landings (Barrett and Gillespie 1973; White and Boudreaux 1977), though there are other, longer-term cycles and trends in the shrimp data as well (Figure 6). But there appears to be little, if any, relationship between the discharge of the Mississippi and the production of the other major commercial species in coastal Louisiana (Figure 7). A cursory examination of landing records from Chesapeake Bay also failed to show any simple relationship with discharge from the Susquehanna River, the major freshwater input to that system.

Regional Variation

If different estuaries are compared, it does not seem to me that the results show any relationship between yield and freshwater input (Table 3). An earlier comparison of seven Texas estuaries by Chapman (1966) reached the opposite conclusion, and he may be correct for the special conditions along the south Texas coast. However, there

Table 3. Annual landings (kg/h) a of finfish and shellfish from various U.S. estuaries.

Estuary	Reference	Finfish	Shellfish	Total
Narragansett Bay (1880)	(1)	63	40	103
Near shore Rhode Island (1975)	(2)	80	31	111
Long Island Sound (1880)	(3)	138	8	146
Long Island Sound (1975)	(4)	29	15	44
Peconic Bay, L.I. (1880)	(5)	85	8	93
Gardiners Bay, L.I. (1880)	(5)	71	8	79
Moriches Bay, L.I. (1880)	(5)	149	58	207
Great South Bay, L. I. (1880)	(5)	110	282	392
Jamaica Bay, L.I. (1880)	(5)	67	51	118
Delaware Bay (1880)	(6)	7	1	8
Delaware Bay (1975)	(7)	1	6	7
Chesapeake Bay (1962)	(8)	142	12	154
Chesapeake Bay (1975)	(7)	132	33	165
Inshore North Carolina (∿1945)	(9)	44	13	57
Apalachicola Bay, F.L. (1966)	(10)	24	54	78
Inshore Louisiana (∿1975)	(11)	113	41	154
Barataria Bay, L.A. (∿1970)	(12)	22	170-440	192-264

1. Clark 1887a
2. N.M.F.S. Area 539, W. Hahm, National Marine Fisheries Service, Woods Hole, Massachusetts
3. Clark 1887b
4. N.M.F.S. Area 611, W. Hahm, National Marine Fisheries Service
5. Mather 1887
6. Collins 1887
7. National Marine Fisheries Service 1975
8. McHugh 1967
9. Taylor et al. 1951
10. U. S. Department of the Interior 1970
11. Bahr et al. 1979 (unpublished manuscript)
12. Day et al. 1973

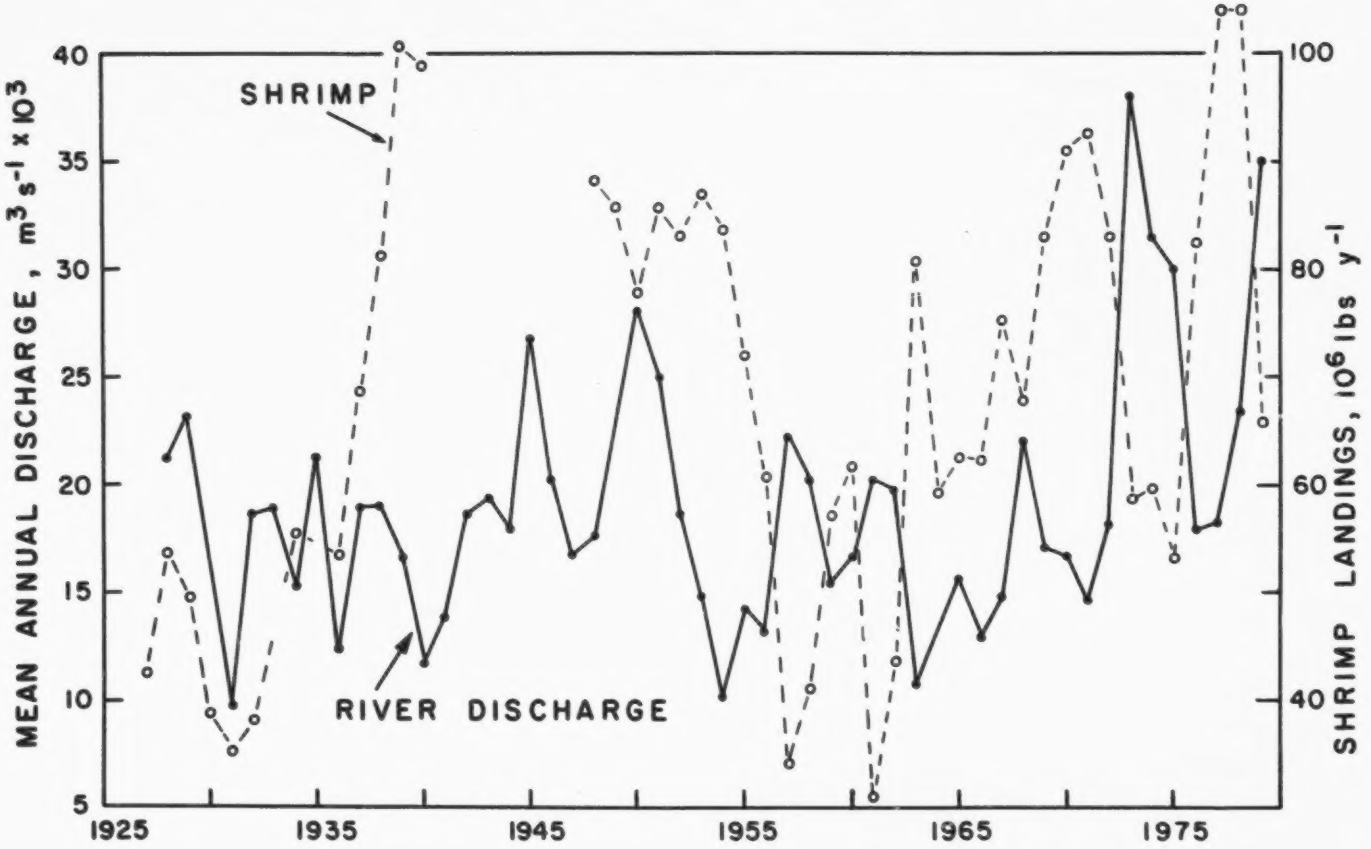

Figure 6. A 50-year record of the mean annual discharge of the Mississippi River and Lousiana shrimp landings.

Table 4. Potential contribution of river nitrogen inputs during winter-spring runoff to the spring-summer phytoplankton bloom in an estuary.

Winter-spring Salinity decrease in the estuary (o/oo)	River water accumulated in estuary (liters/m^3)	Nitrogen increase in the with river nitrogen		Primary production supported in the estuary (mg C/m^3)	
		(10 µM)	(100 µM)	10 µM in river	100 µM in river
35 30	143	0.7	14	55	1075
30 25	167	0.8	16	65	1275
25 20	200	1.0	19	80	1500
25 15	250	1.3	24	105	1900
15 10	330	1.7	31	135	2500
10 5	500	2.5	48	200	3775

[a] Offshore nitrogen = 5 µM

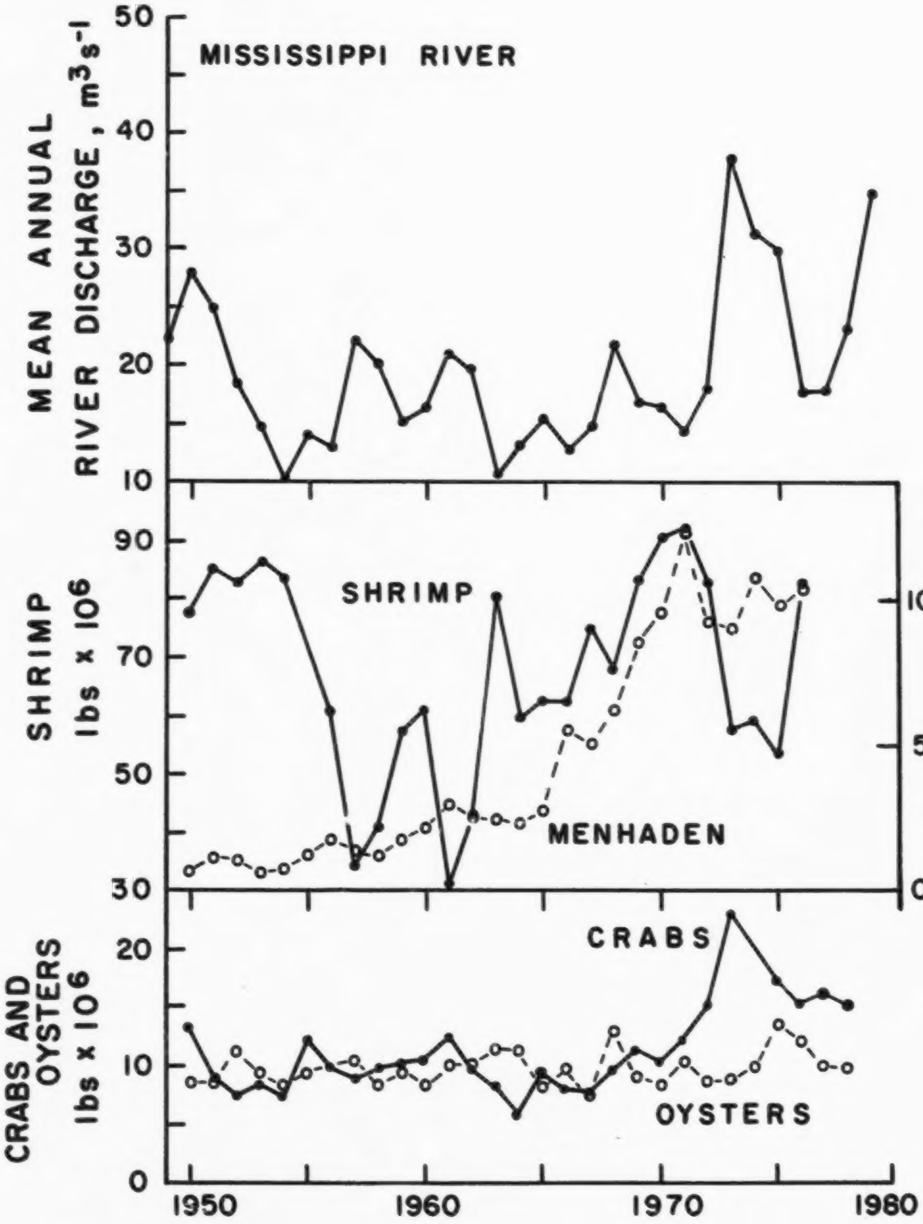

Figure 7. Mean annual discharge of the Mississippi River compared with the Louisiana landings of some estuarine species of major commercial importance.

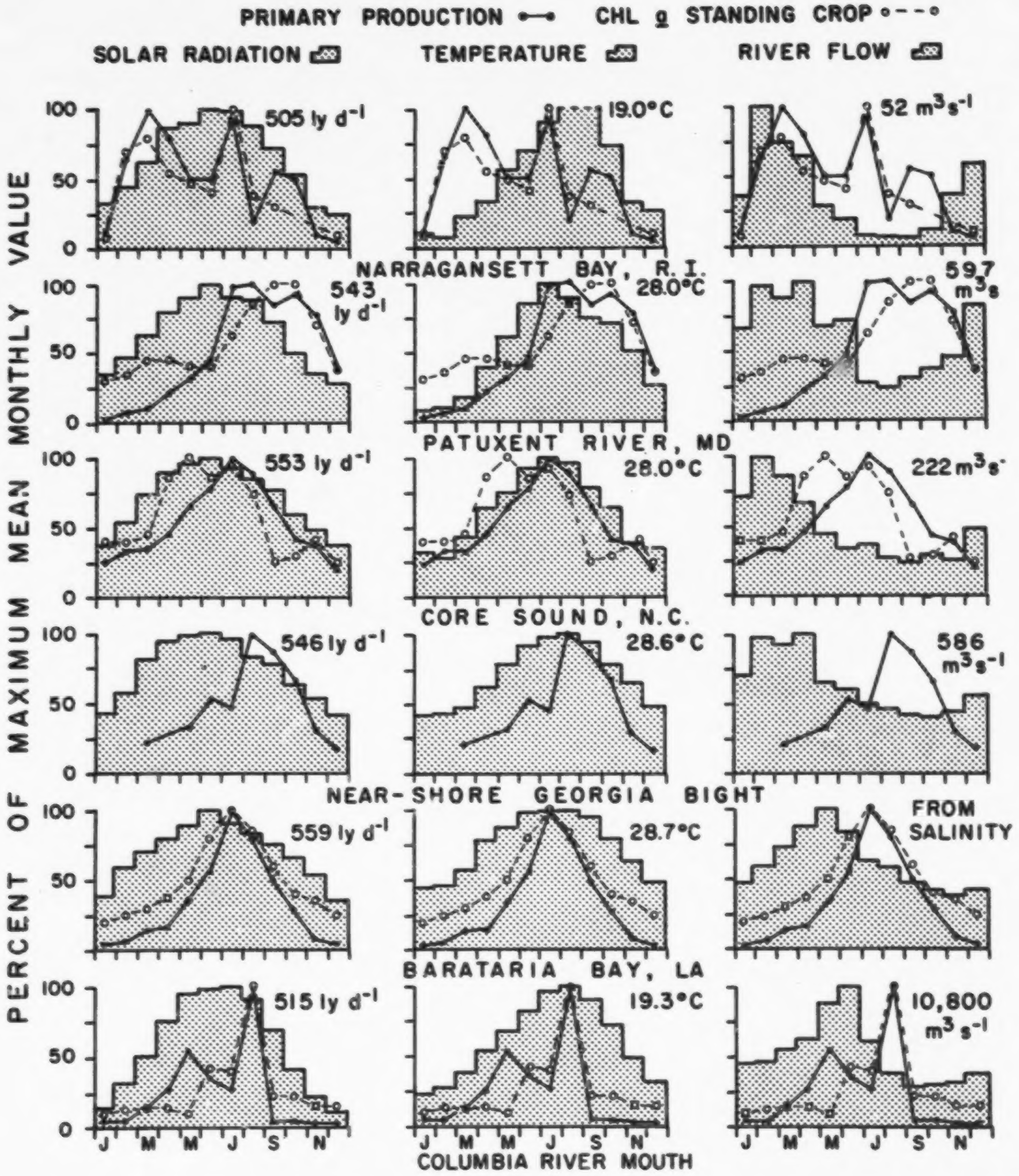

Figure 8. Comparison of the relative seasonal distribution of solar radiation, water temperature, freshwater input, phytoplankton primary production and phytoplankton chlorophyll a (CHL a) in six estuarine and nearshore environments over an annual cycle. Maximum values from which the normalized distributions were calculated are also shown for comparison. Data from sources in text (especially Table 2 and Figures 1 and 2) except as follows: Solar radiation, five-year mean from Climatological Data, National Summary (U.S. Dept. of Comm., Ashville, N.C.); Narragansett Bay plankton data from Durbin et al. (1975); Georgia Bight plankton from Haines and Dunstan (1975).

FRESHWATER INPUT AND

ESTUARINE PRODUCTIVITY

In a few systems, measurements have been made of the annual input of nitrogen from fresh water and other sources and of the annual primary production in the estuary. If a Redfield (1934) model of stoichiometry (106C:16N) is used to calculate the amount of nitrogen required to support the annual production, it appears that, with the exception of some highly eutrophic areas, most of the production must be sustained by recycled nitrogen (Table 5). It may well be that the input of nutrients from fresh water may make some contribution (perhaps an important one) to spring bloom, but for most estuaries, most of the production takes place in the warmer months when recycling is much more important than inputs. I think we will continue to find that this is a general feature of estuarine systems (Nixon 1981), and it helps to explain why estuarine primary production and, to a lesser degree, secondary production levels are so similar. It also helps explain why no one has yet developed diagrams relating nitrogen loading rates to estuarine production as the limnologists have done so successfully with phosphorus loading in lakes (Vollenweilder 1976; Schindler 1981).

The feature that estuaries have in common, and that sets them off from the sea, is that they are shallow. They may have large rivers, or small rivers, or no rivers at all; they may have a great deal of salt marsh or very little; they may have grass beds or seaweed beds or phytoplankton, but they all have their zones of decomposition and nutrient regeneration (both pelagic and benthic) near the euphotic zone. Moreover, there is usually strong vertical mixing from tides and wind to assure that the coupling of decomposition and production is effective. I think it is worthwhile to put forward the hypothesis that the high production of estuarine waters in general is brought about and maintained by the almost complete and rapid coupling of heterotrophic and autotrophic processes. Moreover, if the relative rates of organic synthesis and decomposition are considered, it seems likely that the upper limit of production is set, for the most part, by the slower rate of remineralization. If so, one of the important features of an estuary may be the relative importance of pelagic versus benthic remineralization, because the rate of these processes is quite different. The most rapid way to recycle nutrients is to put the organic matter through pelagic animals, such as microzooplankton. But we need to learn more about the processes of decomposition in the water and in the sediments. Ecologists, like the rest of society, have been preoccupied with production and growth, with the input and consumption of "new" materials. We need to attend more to what Odum et al. (1977) have called the "regenerative half" of our systems.

Now, having said all of that, I must admit to being uncomfortable that the discussion so far has centered on short-term measurements and perspectives. We also know very little about the long-term effects of nutrient input to estuaries. In the short-run, primary production may appear to be supported largely by recycled nutrients, but in the long run, are nutrients being concentrated in the estuaries? Is the recycling rate higher in estuaries with greater input? The similarities of the pri-

Table 5. Comparison of the estimated amount of nitrogen required to support the observed annual primary production with the amount of nitrogen delivered to the estuary in freshwater inputs over the year.

Area	N for annual primary production/annual N input
St. Margaret's Bay, N.S. (Sutcliffe 1972)	8.9[aa]
Narragansett Bay, R.I. (Nixon 1981)	6.9[a] 4.4[b]
Long Island Sound CT. (Harris 1959)	20[aa]
Hudson River Estuary, N.Y. (O'Reilly et al. 1976, Duedall et al. 1976, Thomas et al. 1976a, 4-5 June 1974 1 day budget only)	0.3[a] 0.04[d]
Pamilico River Estuary, N.C. (Kuenzler et al. 1979)	20[a]
Georgia Bight (0-20m) (Haines 1975)	111[a]
San Francisco Bay, CA. (Peterson 1979)	1.3[a] 0.6[c]
Kaneohe Bay, H.I. (Smith 1981)	8[a]

[a] Freshwater flux includes inorganic nitrogen only ([aa]includes only NO_3).

[b] Freshwater flux includes inorganic, dissolved organic and particulate nitrogen.

[c] Freshwater flux includes inorganic and particulate nitrogen.

[d] Hudson River plus inorganic nitrogen in New York City sewage.

mary (and perhaps secondary) production suggest that this is not an important coupling, but we lack long-term data from estuaries, and it is not clear to me how short-term, rapid recycling of nutrients is linked to long-term inputs. The rivers have been flowing for a long, long time, and we know that most estuaries have been filling in with sediment in spite of a rising sea level. But, except for highly enriched urban areas, we do not know if they are also becoming more eutrophic. Freshwater inputs may yet prove to play a role in the long-term fertility of estuaries.

REFERENCES

Anderson, G.C. The seasonal and geographical distribution of primary productivity off the Washington and Oregon coasts. Limnol. Oceanogr. 9:284-302; 1964.

Armstrong, N.E. Effects of altered freshwater inflow on estuarine systems. Fore, P.L.; Peterson, R.D., eds. Proceedings of the Gulf of Mexico Coastal Ecosystems Workshop, 1979, September 4-7, U.S. Dept. of the Interior, Fish and Wildlife Service, Port Aransas, TX. Albuquerque, NM: U.S. Fish and Wildlife Service; 1980:17-31.

Bahr, L.M., Jr.; Day, J.W., Jr.; Stone, J.H. Energy cost-accounting of Louisiana fishery production. Baton Rouge, LA: Center for Wetland Resources, Louisiana State University; 1979 unpublished manuscript.

Barlow, J.P.; Lorenzen, C.J.; Myren, R.T. Eutrophication of a tidal estuary. Limnol. Oceanogr. 8:251-262; 1963.

Barrett, B.B.; Gillespie, M.C. Primary factors which influence commerical shrimp production in coastal Louisiana. New Orleans, LA: Louisiana Wildlife and Fisheries Commission. Tech. Bull. 9; 1973.

Barrett, B.B.; Ralph, E.J. 1977 environmental conditions relative to shrimp production in coastal Louisiana along with shrimp catch data for the Gulf of Mexico. New Orleans, LA: Louisiana Wildlife and Fisheries Commission. Tech. Bull. 26; 1977.

Boynton, W.R. Phytoplankton production in Chincoteague Bay, Maryland. Univeristy of North Carolina; 1974. 142 p. M.S. Thesis.

Bruno, S.F.; Staker, R.D.; Sharma, G.M. Dynamics of phytoplankton productivity in the Peconic Bay estuary, Long Island. Estuarine Coastal Mar. Sci. 10:247-263; 1980.

Carpenter, J. H.; Pritchard, D. W.; Whaley, R.C. Observation of eutrophication and nutrient cycles in some coastal plain estuaries. Eutrophication: Causes, consequences, correctives. Washington, DC: National Academy of Sciences; 1969:210-221.

Chapman, C.R. The Texas Basins Project. Smith, R.F.; Swartz, A.H.; Massman, W.H., eds. A symposium on estuarine fisheries: American Fisheries Society: 1964 September, Atlantic City, NJ. 1966: 83-94

Clark, H.A. The fisheries of Rhode Island. Goode, George Brown and Associates, eds. The fisheries and fishery industries of the United States. Washington, DC:

U.S. Commission of Fish and Fisheries; Government Printing Office; 1887a: 281-310.

Clark, H.A. The coast of Connecticut and its fisheries, Goode, George Brown and Associates, eds. The fisheries and fishery industries of the United States. Washington, DC: U.S. Commission of Fish and Fisheries. Government Printing Office; 1887b: 311-340.

Collins, J.W. Delaware and its fisheries. Goode, George Brown and Associates, eds. The fisheries and fishery industries of the United States. Washington, DC: U.S. Commission of Fish and Fisheries, Government Printing Office; 1887: 407-419.

Copeland, B.J. Effects of decreased river flow on estuarine ecology. J. Water Pollut. Control Fed. 38:1831-1839; 1966.

Correll, D.L. Estuarine productivity. Bioscience. 28:646-650; 1978.

Day, J.W., Jr.; Smith, W.G.; Wagner, P.R.; Stowe, W.C. Community structure and carbon budget of a salt marsh and shallow bay estuarine system in Louisana. Sea Grant Publ. LSU-SG-72-04; 1973. 80p. Available from Louisiana State University, Center for Wetlands Resources, Baton Rouge, LA.

Dillon, C.R. A comparative study of the primary productivity of estuarine phytoplankton and macrobenthic plants. University of North Carolina; 1971.112p. Ph.D. Thesis.

Duedall, I.W.; O'Connors, H.B.; Parker, J.H.; Wilson, R.W.; Robbins, A.S. The abundances, distribution and flux of nutrients and chlorophyll $\underline{a}$ in the New York apex. Nesa, National Oceanographic and Atmospheric Administration. Final report, part 1. 1976.

Durbin, E.G.; Krawiec, R.W.; Smayda, T.J. Seasonal studies on the relative importance of different size fractions of phytoplankton in Narragansett Bay (USA). Mar. Bio. 32: 271-287; 1975.

El-Sayed, S.Z. et al. Chemistry, primary productivity,and benthic algae of the Gulf of Mexico. Serial atlas of the marine environment, Folio 22. American Geographical Society; 1972.

Furnas, M.J.; Hitchcock, G.L; Smayda, T.J. Nutrient-phytoplankton relationships in Narragansett Bay during the 1974 summer bloom. Wiley, M.L. ed. Estuarine processes, Vol. 1, Uses, stresses and adaptation to the Estuary. New York: Academic Press; 1976: 118-134.

Haines, E.B. Nutrient inputs to the coastal zone: the Georgia and South Carolina Shelf. Cronin L. E., ed. Estuarine research, Vol. 1. New York: Academic Press; 1975: 303-322.

Haines, E.B. Interactions between Georgia salt marshes and coastal waters: a changing paradigm. Livingston, R.J., ed. Ecological processes in coastal and marine systems. Proceedings of the symposium at Florida State University, April 1978. Plenum Press; 1979a: 35-46.

Haines, E.B. Nitrogen pools in Georgia coastal waters. Estuaries 2:34-39; 1979b.

Haines, E.B.; Dunstan, W.M. The distribution and relation of particulate organic material and primary productivity in the Georgia Bight, 1973-1974. Estuarine Coastal Mar. Sci. 3:431-441; 1975.

Harris, E. The nitrogen cycle of Long Island Sound. Bull. Bingham Oceanogr. Coll. 17: 31-65; 1959.

Harrison, W.G.; Hobbie, J. E. Nitrogen budget of a North Carolina estuary. Chapel Hill, NC: Water Resources Research Institute, University of North Carolina: Rep. 86; 1974. 172p.

Hitchcock, G.; Smayda, T.J. The importance of light in the initiation of the 1972-1973 winter-spring diatom bloom in Narragansett Bay. Limnol. Oceanogr. 22:126-131; 1977.

Ho, C.L.; Barnett, B.B. Distribution of nutrients in Louisiana's coastal waters influenced by the Mississippi River. Estuarine Coastal Mar. Sci. 5:173-195; 1977.

Huntsman, A.G. Effect of freshets on Passamaquoddy plankton. Deep-Sea Res. Suppl. to Vol. 3; 1955; 321-330.

Jaworski, N.A. Sources of nutrients and the scale of eutrophication problems in estuaries. International symposium on the effects of nutrient enrichment in Estuaries, 1979 May 29-31; Williamsburg, VA. Humana Press. In press.

Ketchum, B.H.; Keen, D.J. The accumulation of river water over the continental shelf between Cape Cod and Chesapeake Bay. Deep-Sea Res., Suppl. to Vol. 3; 1955; 346-357.

Kjerfve, B.; Greer, J.E.; Crout, R.L. Low-frequency response of estuarine sea level to non-local forcing, Wiley, M.L. ed. Estuarine interactions, New York: Academic Press; 1978: 497-513.

Kuenzler, E.J.; Stanley, D.W., Keonings, J.P. Nutrient kinetics of phytoplankton in the Pamlico River, North Carolina. Chapel Hill NC: Water Resources Research Institute, University of North Carolina; Rep. 139; 1979. 163p.

Livingston, D.A. The chemical composition of rivers and lakes. Fleischer, M. ed. Data of geochemistry, 6th ed. U.S. Geological Survey Professional Paper 440; 1962.

Malone, T. C. Phytoplankton productivity in the apex of the New York Bight: Environmental regulation of productivity/chlorophyll a. The Middle Atlantic Shelf and New York Bight. Gross, M.G., ed. Limnology and Oceanography Special Symposium 2; 1976.

Malone, T. C. Environmental regulation of phytoplankton productivity in the lower Hudson estuary. Estuarine Coastal Mar. Sci. 5:157-171; 1977.

Mandelli, E.F.; Burholder, P.R.; Donheny, T.E.; Brody. R. Studies of primary productivity in coastal waters of southern Long Island, New York. Mar. Biol. 7:153-160; 1970.

Mann, K. H. Ecological energetics of the seaweed zone in a marine bay on the Atlantic coast of Canada. II. Productivity of the seaweeds. Mar. Biol. 14:199-209; 1972a.

Mann, K.H. Macrophyte production and detritus food chains in coastal waters. Mem. Ist. Ital. Idrobiol. (Suppl. 29): 353-383; 1972b.

Mather, F. New York and its fisheries. Goode, George Brown and Associates eds. The fisheries and fishery industries of the United States. Washington, DC: U.S. Commission of Fish and Fisheries, Government Printing Office; 1887.

McHugh, J.L. Estuarine nekton, Lauff, H. ed. Estuaries. Washington, DC: American Association for the Advancement of Science; 1967: 581-620.

National Marine Fisheries Service. Fishery Statistics of the United States, Washington, DC: U.S. Department of Commerce, NOAA; 1975.

Nixon, S.W. Remineralization and nutrient cycling in coastal marine ecosystems. International symposium on nutrient enrichment in estuaries. 1979 May 29-31; Williamsburg, VA: Humana Press. 1981.

Nixon, S.W. The coupling of coastal salt marshes and offshore waters--a review of twenty years of speculation and research on the role of salt marshes in estuarine productivity and water chemistry. Hamilton, P.; MacDonald, K. eds. Estuarine and wetland processes. New York: Plenum Publishing Co.; 1980:437-525.

Nixon, S.W.; Lee, V. The flux of carbon, nitrogen and phosphorus between coastal lagoons and offshore waters. Lassier, P. ed. Ecology of Coastal Lagoons. UNESCO Tech. Publ. in Marine Science. In press.

Nixon, S.W.; Oviatt, C.A.; Kremer, J. N.; Perez, K. The use of numerical models and laboratory microcosms in estuarine ecosystem analysis-simulations of a winter phytoplankton bloom. Dame, R.F. ed. Marsh-estuarine systems simulation. Columbia, SC.: University of South Carolina Press, 1979: 165-188.

Odum, E.P. A research challenge: evaluating the productivity of coastal and estuarine water. Proceedings 2nd sea grant Conference; 1968: 63-64. Available from: Graduate School of Oceanography, University of Rhode Island, Newport, RI.

Odum, H.T.; Nixon, S.W.; DiSalvo, H. H. Adaptations for photoregenerative cycling. Cairns, J. Jr., ed. Aquatic microbial communities. New York: Garland Publishing, Inc.; 1977: 1-39.

O'Reilly, J.E.; Thomas, J.P.; and Evans, C. Annual primary production (nannoplankton, netplankton, dissolved organic matter) in the lower New York Bay. McKeon, W.H.; Lauer, G.J., eds. Fourth symposium on Hudson River ecology. New York: Hudson River Environmental Society, Inc.; 1976.

Peterson, D.H. Sources and sinks of biologically reactive oxygen, carbon, nitrogen, and silica in northern San Francisco Bay, Conomos, T.J. ed. San Francisco Bay: the urbanized estuary. Lawrence, KS: Allen Press; 1979: 175-193.

Platt, T. The annual production of phytoplankton in St. Margaret's Bay, Nova Scotia. J. Cons. Int. Explor. Mer. 33:324-334; 1971.

Platt, T. Analysis of the importance of spatial and temporal heterogeneity in the estimation of the annual production by phytoplankton in a small, enriched, marine basin. J. Exp. Mar. Biol. Ecol. 18: 99-109; 1975.

Redfield, A.C. On the proportions of organic derivatives in sea water and their relation to the composition of plankton. James Johnstone Memorial Volume. Liverpool: Liverpool University Press; 1934: 176-192.

Redfield, A.C.; Ketchum, B.H.; Richards, F.A. The influence of organisms on the composition of sea-water. Hill, M.N. ed. The sea, Vol. 2. New York: Wiley Interscience; 1963: 26-77.

Riley, G.A. Phytoplankton of Block Island Sound. Bull. Bingham Oceanogr. Collect. 8(3):40-64; 1952.

Riley, G.A. Review of the oceanography of Long Island Sound. Deep-Sea Res. Suppl. to Vol. 3: 224-238; 1955.

Riley, G.A. Oceanography of Long Island Sound, 1952-1954. Physical Oceanography. Bull. Bingham Oceanogr. Coll. 15:15-46; 1956.

Riley, G.A. Mathematical model of nutrient conditions in coastal waters. Bull. Bingham Oceanogr. Coll. 19:72-80; 1967.

Ryder, R.A. A method for estimating the potential fish production of north-temperate lakes. Trans. Am. Fish. Soc. 94:214-218;1965.

Ryther, J.H.; Yentsch, C.S. Primary production of continental shelf waters off New York. Limnol. Oceanogr. 3(3):327-335; 1958.

Ryther, J.H.; Menzel, D.W.; Corwin, N. Influence of the Amazon River outflow on the ecology of the western tropical Atlantic. I. Hydrography and nutrient chemistry. J. Mar. Res. 25:69-83;1967.

Sellner, K.G.; Zingmark, R.G.; Miller, T.G. Interpretations of the ^{14}C method of measuring the total annual production of phytoplankton in a South Carolina Estuary. Bot. Mar. 19:119-125; 1976.

Schindler, D.W. Eutrophication in lakes and its relevance to the estuarine environment. Proc. international symposium on nutrient enrichment in estuaries, 1979 May 29-31; Williamsburg, VA. Humana Press 1981.

Sheridan, P.F.; Livingston, R.J. Cyclic trophic relationships of fishes in an unpolluted, river-dominated estuary in North Florida. Livingston, R.J., ed. Ecological processes in coastal and marine systems. New York: Plenum Press; 1979:143-161.

Sklar, F.H. Primary productivity in the Mississippi Delta Bight near a shallow bay estuarine system in Louisiana. Baton Rouge, LA: Louisiana State University; 1976. 210p. M.S. Thesis.

Smith, S.V. Responses of Kaneohe Bay, Hawaii to relaxation of sewage stress. Proceedings International Symposium on nutrient enrichment in estuaries. May 29-31; 1979. Williamsburg, VA. Humana Press. 1981.

Stockner and Cliff. Phytoplankton ecology of Vancouver Harbor. J. Fish Res. Board Can. 36:1-16; 1979.

Stross, R.G. and Stottlemeyer, J.R. Primary production in the Patuxent River. Chesapeake Sci. 6: 125-140; 1965.

Sutcliffe, W.H., Jr. Some relations of land drainage, nutrients, particulate material and fish catch in two eastern Canadian bays. J. Fish. Res. Board Can. 29:357-362.; 1972.

Sutcliffe, W.H., Jr. Correlations between seasonal river discharge and local landings of American lobster (Homarus americanus) and Atlantic Halibut (Hippoglossus hippoglossus) in the Gulf of St. Lawrence. J. Fish. Res. Board Can. 30:856-859; 1973.

Taylor, H.F. and Associates. Survey of marine fisheries of North Carolina. Chapel Hill, NC Univ. of North Carolina Press; 1951.

Thayer, G.W. Phytoplankton production and the distribution of nutrients in a shallow unstratified estuarine system near Beaufort, N.C. Chespeake Sci.12(4):240-253; 1971.

Thayer, G.W. Identity and regulation of nutrients limiting phytoplankton production in the shallow estuaries near Beaufort, N.C. Oecologia (Berl.) 14:75-92. 1974.

Thomas, J. P. The influence of the Altamaha River on primary production beyond the mouth of the river. Athens, GA: Department of Zoology, University of Georgia; 1966. M.S. Thesis.

Thomas, J.P.; Phoel, W.; O'Reilly, J. E.; Evans, C. Seabed oxygen consumption in the Lower Hudson Estuary. McKeon, H.; Lauer, G.J. eds. Fourth Symposium on Hudson River ecology, New York: Hudson River Environmental Society, Inc.;1976a.

Thomas, J.P.; Phoel, W.C.; Steimle, F.W.; O'Reilly, J.E. and Evans, C.A. Seabed oxygen consumption-New York Bight apex. Am. Soc. Limnol. Oceanogr., Special Symposia, Vol. 2:354-369; 1976b.

Turner, R.E.; Woo, S.W.; Jitts, H.R. Phytoplankton production in a turbid temperate salt marsh estuary. Estuarine Coastal Mar. Sci. 9:603-613; 1979.

Udell, H.F.; Zarudsy, J.; Donheny, T. E.; Burkholder, P.R. Productivity and nutrient values of plants growing in the salt marshes of the town of Hempstead, Long Island. Bull. Torrey Bot. Club 96:42-51; 1969.

UNESCO. Discharge of selected rivers of the world, Vol. III (part II), Mean monthly and extreme discharges (1969-1972). France: The Unesco Press; 1974.

U.S. Department of Commerce. Surface water temperature and salinity Atlantic coast, North and South America. C & GS Publication 31-1, First Edition; 1960.

U.S. Department of Interior, Fish and Wildlife Service. National Estuary Study, Vol.3. U.S. Government Printing Office; 1970. 326 pp.

Vollenweider, R.A. Advances in defining critical loading levels for phosphorus in lake eutrophication. Mem. Ist. Ital. Idrobiol. 33:53-83; 1976.

Whaley, R.C.; Carpenter, J.H.; Baker, R. L. Nutrient data summary 1964, 1965, 1966: upper Chesapeake Bay (Smith Point to Turkey Point); Potomac, South, Severn, Magothy, Back, Chester, and Miles Rivers; and Eastern Bay. Chesapeake Bay Institute, The Johns Hopkins University, Special Report 12, Reference 66-4; November 1966.

White, C.J. Boudreaux, C.J. Development of an areal management concept for Gulf penaeid shrimp. New Orleans, LA: Louisiana Wildlife and Fisheries Commission. Tech. Bull. 22; 1977.

Winter, D.F.; Banse, K.; Anderson, G. C. The dynamics of phytoplankton blooms in Puget Sound, a fjord in the northwestern United States. Mar. Biol. 29:139-176; 1975.

PLENARY PANEL

POLICIES AND PROBLEMS IN DEALING WITH FRESHWATER INFLOW TO ESTUARIES

Chaired by

Mr. John Clark, Conservation Foundation

INTRODUCTION

John Clark

Conservation Foundation, Washington, D.C.

Many years ago, the Conservation Foundation discovered that estuaries were a valuable resource; one that was vulnerable because of the inevitable navigation, industrial, and general residential development that occurs along our shores. In a book produced during the late fifties by Lionel A. Walford--Living Resources of the Sea--the Conservation Foundation made its pitch for the estuary as an endangered resource that vitally needed protection. The Foundation began an aggressive effort to protect wetlands and waters of estuaries as intact resource units. One mistake made was to think that estuarine conservation was largely a coastal problem. It may have been a coastal problem in the sixties when dredging and filling were occurring and wetland destruction was rapid. But now, with most of the worst of those destructive kinds of projects under control, we find that estuarine conservation is largely a water supply problem dealing with the quantity, the quality, the timing, and the rate of flow. This is where the scene has shifted and this is where we are going to have to work if we are going to protect estuaries. We have to know how much water is needed, what pollutants are tolerable, and at what times these waters flow into estuaries. As a result of this shift from concerning ourselves with the coastal area, to the water basin itself and the physical changes there, just about everything we have done in the conservation of estuaries since 1965, when Congress started trying to get its estuarine legislation together, is all out of date. For instance, the Coastal Zone Management program in this country, which was fashioned to protect estuaries, is powerless to cope with issues about water supply to estuaries. I don't know how many of you know it, but the first version of the Coastal Zone Management Act in 1969 and early seventies was known as the Estuarine and Coastal Zone Management Act. It was a resource protection initiative fashioned in Congress. Somehow in the next couple of years, before 1972, it got wrenched around strongly to becoming a land use oriented management act. Meanwhile, separate Federal programs and permit programs were devising some pretty good controls over dredging, filling, and wetland destruction. Because the Coastal Zone Management Act is powerless to do anything about water supply, quantity, quality, and timing a new initiative is needed for estuarine conservation. This initiative must have its roots in national water resources policy, not in coastal policy. This shadowy area is what Gary Wills calls the sunless marshlands of American politics.

FRESHWATER INFLOW AND CHESAPEAKE BAY

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I am very pleased to discuss a few of the problems and policies associated with freshwater inflow to estuaries. Even though the subject is extremely broad and very diverse, I have directed my comments to the problems created from the competition between man and estuaries for freshwater inflow. From the context of this presentation, I am using the term problem not to suggest an adverse effect as a result of change, but rather only to indicate that a change has taken place.

The largest estuary in North America, of course, is the Chesapeake Bay. It is 695 miles long from the flats at the mouth of the Susquehanna River to its mouth at Hampton, Virginia. It varies in width from 4.2 miles to approximately 37.5 miles and contains an average of 18 trillion gallons of water. The total drainage area for the bay is approximately 64,000 square miles. Forty-two percent of this is the Susquehanna drainage basin and another 22 percent comes from the Potomac River Basin. In all, the Chesapeake Bay drains six states and Washington, D.C. Of the total volume of freshwater inflow, which averages approximately 69,000 cubic feet per second, the Susquehanna contributes 70 percent. There are approximately 2,700 species of mammals, birds, fish, and reptiles that have at one time or another been found around the bay. Among these are numerous species of resident and migratory fish and waterfowl which are dependent upon the Chesapeake estuary for all or a significant part of their life. The spawning of indigenous fish in the Chesapeake waters contributes greatly to the Atlantic coast stocks. This is especially true of striped bass. Researchers have estimated that 8 percent of the Atlantic coast striped bass population is spawning in Maryland.

As we are aware, the indigenous life associated with estuaries must share their water with our expanding human population. Recent estimates by the Army Corps of Engineers indicate that by the year 2020, the existing population around the Chesapeake Bay will double. This will mean an increase from an existing eight-plus million population to over 16 million people, most of whom will be competing for their share of the water. Commercial fishing, maritime transportation, and a wide range of recreational activities are examples of man's various water-dependent activities. Estuaries are also expected to provide water for municipal and industrial waste. This, of course, is not unique to estuaries. Rivers, streams, and lakes and the inland regions are also confronted with these demands. Man treats all waterways with equal disregard. Fish, waterfowl, and aquatic plants must also compete daily for their fair share. If we were to look at a map of the eastern United States, we would see that most major urban areas are located adjacent to an estuary. New York City on Raritan Bay, Philadelphia on the Delaware Bay, and the Newport News complex on the Chesapeake are examples. There is no reason not to expect that these urban areas will not have the same or similar population increases as was already referenced for the Chesapeake region. Recently much discussion has been given to an apparent trend in declining resources of the Chesapeake estuary. The temporary closure of the shad fishery, poor reproduction of the oyster, reduced recruitment to the striped bass spawning stocks, and significant declines in submerged aquatic vegetation have caused considerable concern. We are looking for explanations for these occurrences. Several research efforts have been directed at the problems associated with changes in the inflowing fresh water. There is no need for any further discussion of these projects since several papers at this symposium will treat these subjects.

Estuaries have both quantitative and qualitative problems associated with changes in freshwater inflow. Even estuaries with little or no urbanization in their watersheds have freshwater inflow problems, resulting primarily from natural events such as tropical storm Agnes in 1972 and Hurricane Allen earlier this year which carried large amounts of sediments to Chesapeake Bay. In estuaries that are highly urbanized, man's influence has exacerbated these problems. Let's now examine these problems a little more closely. Quantitatively, one of the first problems that we are confronted with is the restrictions to freshwater inflow. Restrictions can generally occur as a result of dams and weirs which are located primarily to provide water storage for municipal uses, electric power generation, recreational uses, or agricultural purposes such as irrigation. Problems associated with these uses simply are a reduction of the amount of fresh water flowing into an estuary. A current example of one of the potential problems that exists in Maryland is the relicensing of the Conowingo Dam. The Conowingo is up for its fiftieth relicensing. As a part of this relicensing effort, a study is underway to determine what the minimum continuous discarge from the Conowingo Dam should be so that a condition can be placed on the license to ensure an adequate supply--in particular for spawning fish such as shad and striped bass--of water below the dam. Another quantitative problem is the consumptive use of water for municipal and industrial purposes. Under normal conditions, these withdrawals are, perhaps, not as significant in the Chesapeake or on the east coast as they are in some areas of California. Major concerns, however, are created when freshwater inflow is reduced as a result of drought conditions. To address this situation, Maryland, Virginia, and the District of Columbia have entered into an allocation agreement. Let me read to you an excerpt from the draft plan: "Maryland is recognized as owning the Potomac River bottom to the low water line on the Virginia side of the river. Although Maryland ceded to the Congress of the United States a district of ten miles square to be used for the seat of the Federal Government, the transfer of ownership and a later consent given to appropriation of surface waters for supply to the city of Washington did not relinguish Maryland's sovereignty over the waters. Instead the Federal entity is considered by Maryland as a lower riparian user. Maryland's authority over the Potomac withdrawals under riparian permit system is not to allow it to deprive the District of Columbia or any other riparian users reasonable use of river waters. Maryland, therefore, is to ensure that an adequate supply of water is available to the competing interests within the framework of

PROBLEMS OF FRESHWATER INFLOW PLANNING IN CALIFORNIA

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I will divide my presentation on policy into three parts. First, I will address the policy of the Water and Power Resources Service in terms of estuarine inflow. Second, I will speak of the problems of implementing that policy, and third, I will discuss the method of implementation of that policy in California. The policy of the Water and Power Resources Agency is simple. It says that we will mitigate project-caused damages to the biological community. A corollary to that is that water resources projects do have an effect upon the estuarine environment. That is clear. If the policy is so clear, you may ask, then why don't we just implement it and get on about our business? That brings us to the problems associated with implementation of policy. First, there is difficulty in defining the problem. We plan to build a dam on river X and we go to the Fish and Wildlife Service, in accordance with the Coordination Act, and we tell them of out intentions and request to know exactly what the consequences of that action will be. The Fish and Wildlife Service does their best and explains that they know some of the consequences but there are some things they cannot predict. If things were done properly, we wouldn't build the dam because there are many things we don't know. But that is not the way it is. We accept Fish and Wildlife's report and build the dam. Later the Fish and Wildlife Service reports to us that there are now certain factors about the dam that were not known initially but are known now. But, the dam has been built and is functioning. So the information we didn't have initially is now useless. That brings us to problem number two.

The Water and Power Resources Services is governed by law. The Congress of the United States assigns tasks for us to do, and regardless of how I feel morally, regardless of how the Secretary of the Interior feels morally, we must go by the law. As an example I will site the case of the United States vs California. If a state requests us to do a project for them, we can do it as long as it does not violate a Federal law. We may have to go to court in order to convince the state that the Federal Government is not subservient to state law. We all believe that certain things ought to be done, but if the law doesn't provide for it, we can't do it. So the only alternative is to change the law and that is what will have to be done in this case. That brings us to problem two-and-a-half. Lawyers, once they get into the act, forget what the problem is. So consequently, we have been going around and around in the courts on a problem that ought to be solved, but once it is in court we are dealing with the law and not the issue at hand. That brings up problem number three. Shasta Dam, for example, is there. It isn't going anywhere, it is going to be there forever. Now, what we do with Shasta Dam is another issue. At the current time, Shasta Dam's yield and reservoir storage is committed by law to some other use. We have contracts signed; we have water that is being diluted; we have an economy that is based on that water; we have farmers that need water, etc. Now, if the problems that face our estuary are going to be solved, they are not going to be solved with Shasta Dam, because the water from Shasta is already committed.

That brings us to problem number four, which is the policy of this agency and the policy of the Secretary of the Interior in terms of what ought to be accomplished in solving the problems of the estuaries. However, that policy is subject to interpretation based on the needs at the time, So, we plan to mitigate for all the project damages but, if a problem arises, the Secretary may decide on one course of action. In so doing, his office may look at the very same policy and decide on a whole new direction. That is something that we need to recognize and deal with at staff level, even though we have little to do with the decision. I promised to present some solutions to these kinds of dilemmas and I think it was done in the proper manner in the State of California. We have formed a four agency group which consists of the Water and Power Resources Service, California Department of Fish and Game, California Department of Water Resources, and the Fish and Wildlife Service. Together, we formulate local policies that address issues we need to deal with. We recognize that there is a general policy for all agencies, but working together we can offer solutions to the problems that confront us. In conclusion, I would like to say that nature forever changes for its own reasons. Now, some changes we understand and some we do not, and the approach to the management of nature has been to keep it static. That my friends, is the paradox of our biggest problem.

Something I think is quite important for us to recognize and a very, very simple precept is that there are some people around this room who minimize or question the need for freshwater inflow to estuaries. There are many people who are fully convinced that we need the total amount of water going to these estuaries that we have discussed. The size of an estuary is a very important function of its total ability to put out products, to supply the needs that we are here to talk about. Now, in many estuarine basins, if not most, the effective size of an estuary is directly proportional to the amount of fresh water going in. Here is how that works, if you use, for instance, five to fifteen parts per thousand of salinity as the essential part of the richest segment of the estuarine basin? You can have an average of four acre-feet of this prime estuary for every one-acre-foot of dilution. So, if you put in ten acre-feet of dilution, you have forty acre-feet of estuary and so on, it is directly proportional. I think it is very important to think that it is not only the quality of the estuary that relates to the amount of freshwater inflow, but its size.

Maryland's sovereign authority to regulate the appropriation of Potomac water within its boundaries." I must add that competing interests also include the fish and resources as part of that system. To support this assurance, Maryland legislative approval is a necessary prerequisite to any withdrawal of water. A study as part of this allocation agreement is underway to determine what water can flow into the lower Potomac. The results of this study will, of course, be taken into consideration in any agreement that is finalized between the signatories. The third form of quantitative problems associated with urbanization on freshwater inflow is interbasin transfers. Although this is not a significant problem in Maryland, there are two instances where the potential for interbasin transfer exists and another one is under consideration. In other areas of the country, this may be of a greater concern.

The other problem associated with the inflow of fresh water and man's use of it is the quality of the water flowing into the estaury. There are many problems associated with water quality, but the majority of the problems stem from urbanization and agriculture. There is a great deal of work going on now to determine what is the exact quantity of agricultural activity that really adds to the problem of water quality as associated with the flowing waters.

The primary concern with urbanization is the sediment loading resulting from development. Another aspect is nutrient enrichment. Nutrient enrichment resulting from the discharge from municipal sewage treatment plants is an example. It is interesting to note that in a qualitative sense, the withdrawal of water for municipal and industrial uses can also create a quality problem at the other end of the pipe in terms of the discharge from industries by adding pollutants and other toxic substances and nutrient enrichment from sewage treatment plants. Additionally, the whole concept of land use change from a vegetated to a paved area increases the surface water run-off which may in fact lead to increased sediment load. The consequences of these kinds of problems can be broken into three basic groups. Natural consequences include the fluctuations in the salt wedge within the estuary, the altered usability of the water for aquatic resources, the volume of water, the seasonal timing of inflow, and the changes in sediment loading as it relates to the spawning of anadromous fish and resident fish. Another consequence related to the social-political arena are decisions related to the competition between human resources and indigenous resources; these all must be resolved in order to maintain a healthy environment. Lastly, we have jurisdictional consequences. These relate to the willingness of an upstream user to pay for the problem he is creating downstream out of his jurisdication. The Maryland coastal zone program goals related to freshwater inflow can be summarized as follows: to maintain or enhance the quality of estuarine water and to ensure an adequate supply of water for the indigenous aquatic resources. The on-going research in the Chesapeake Bay, some of which will be presented over the next few days, is designed to provide necessary information to make this goal a reality.

MANAGEMENT OF FRESHWATER INFLOW TO ESTUARIES: A LAWYER'S PERSPECTIVE

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Rivers and their associated floodplains are integrally related to the estuaries into which they discharge. The chemical, physical, and biological conditions of any estuary are significantly influenced by those same characteristics of surface and ground freshwater inflow. The condition of surface and ground water inflows is therefore of critical importance where the maintenance or restoration of the chemical, physical, and biological functioning of an estuary is a recognized objective.

Maintenance of freshwater inflow systems as part of an estuarine management program is hampered by three factors--(1) Federal statutory programs which fail to recognize the interrelationships between riverine and estuarine systems; (2) inadequate scientific knowledge of these relationships; and (3) Federal water resource development programs that continue to promote massive alteration of riverine systems, including floodplain vegetation. Although existing statutory programs can be effective in controlling discharges of some pollutants into surface or ground waters entering estuaries, they are not so effective at controlling major alterations of freshwater inflows, such as hydrologic modifications, alterations in sediment patterns, and loss of riverine wetland floodplain vegetation, which affect estuaries. These legal constraints are also a reflection of the state of scientific knowledge about riverine-estuarine relationships. Increased scientific knowledge about these relationships will be useful in strengthening the effectiveness of existing programs to combat degradation of freshwater flows to estuaries.

MAJOR FEDERAL STATUTES AFFECTING FRESH WATER FLOWS ENTERING ESTUARIES

Several Federal statutes address the subject of freshwater aquatic systems and estuaries. Key statutes include the Clean Water Act, the National Environmental Policy Act, the Costal Zone Management Act, as amended by the Coastal Zone Management Improvement Act of 1980, and the Fish Conservation Policy Act. However, in significant respects these statutes do not and have not been administered effectively to maintain or restore the quality and quantity of freshwater flows to estuaries as part of a concerned program to protect those estuaries.

The objective of the Clean Water Act, 33 U.S.C. S1251(a), is the maintenance and restoration of the chemical, physical, and biological integrity of the Nation's waters. These waters clearly encompass estuaries and freshwater flows to those estuaries.[1] The National Environmental Policy Act, 42 U.S.C. S4221, also provides national environmental policy guidelines in how Federal actions should affect ecosystems. Because many Federal water resource and energy projects typically modify the flows of fresh water to estuaries, NEPA, together with other statutes and regulations which govern planning for such projects, could, in theory, be used to maintain those flows. In addition, recognition in the Fishery Resources Management Act of 1976, 16 U.S.C. S1801, of the importance of fishery habitats for maintenance of fish stocks is implicit Congressional acknowledgement of the necessity to protect estuaries.

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[1] The Federal Clean Water Act describes programs affecting ground

In salient respects, however, these acts provide governmental agencies at the state or Federal level with only very limited authority to maintain, protect or restore the chemical, physical and biological conditions of surface and ground freshwater flows as they affect estuaries. In terms of the Clean Water Act, so much of the degraded hydrologic and quality conditions of freshwater flows to estuaries is categorized as non-point source pollution. Second, although ground water flows affect estuaries, Federal and state programs in general are not effective at regulating withdrawals of ground water which may affect estuaries. Furthermore, programs to protect ground water quality through regulation of discharges to ground water are just now being implemented, and, in general, they do not consider the effect of polluted ground water on estuarine resources.[2] Third, Federal environmental legislation cannot undo the massive ecological impacts of Federal water projects.[3]

Finally, the jurisdictional scope of broad legislation designed to protect coastal resources, such as the Fish Conservation and Management Act of the Coastal Zone Management Improvement Act of 1980, is generally too limited to provide a basis for management of freshwater inflows to estuaries. Under the Fish Conservation and Management Act, 16 U.S.C. S1801, although the fishery management councils have the authority to make recommendations for inshore estuarine or fresh water habitats which function as nursery or spawning grounds or food sources for

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water, including implicitly ground water flows to estuaries, in Sections 102(a) and 208(b) (2) (K), 33 U.S. S1252(a) and over ground water has not been clearly resolved administratively or judicially. See, Tripp and Jaffe, "Preventing Ground Water Pollution: Towards A Coordinated Strategy to Protect Critical Recharge Zones," 3 Harv. Env. L. Rev. 1, 13-20 (1979).

[2] Federal and related state programs affecting groundwater quality arises under the Resource Conservation and Recovery Act, U.S.C. S6901-6907; the Safe Drinking Water Act, 42 U.S.C. S300f to j-9. For a discussion of the potential impact of nitrate contamination in groundwater as it affects estuarine shellfisheries, see Durand, James B., *Nutrient and Hydrological Effects of the Pine Barrens on Neighboring Estuaries*, p. 195, in Forman, R.T.T., ed. *Pine Barrens: Ecosystem and Landscape*, 1979, Academic Press, N.Y.

[3] Federal laws, regulations and directives applicable to the planning of Federal water resource projects include the 1965 Water Resources Planning Act, 42 U.S.C. S1962 and Sections 315, 401, 402, and 404 of the Clean Water Act, 33 U.S.C. S1323, 1341, 1342, and 1344.

The enforcement potential of the designated programs is influenced by a number of factors, including administrative interpretation of key provisions of the statutes in question, adminstrative willingness to utilize statutory enforcement provisions, judicial interpretations, the advance of scientific knowledge and the effectiveness of beneficiary groups, such as fishermen, shellfishermen, hunters and recreationists, in expressing their political will.

MAJOR PROBLEM AREAS WHICH EXISTING REGULATORY PROGRAMS DO NOT EFFECTIVELY ADDRESS

Table 1 indicates that some of the pollutant/pollution types and sources affecting the quantity and quality of freshwater inflows to estuaries have been identified and are being regulated under existing programs. These include reductions in BOD which affects dissolved oxygen levels, pathogens and, perhaps to a lesser degree, nutrients. In addition, regulatory programs operated under Section 10 of the 1899 Rivers and Harbors Act, 33 U.S.C. S403, and Section 404 of the Clean Water Act, 33 U.S.C. S1344, have reduced non-federal discharges of dredged or fill material into waters of the United States, including wetlands, in particular discharges associated with non-water dependent activities. Together with Executive Orders 11988, 11990, these same programs have, futhermore, to a limited degree, beneficially altered patterns of discharge of dredged and fill material associated with Federal water resource development and other infrastructure projects.

On the other hand, as the table indicates, major types and sources of pollution of freshwater inflows which degrade estuaries are subject to ineffective regulation; indeed, on the contrary, major economic incentives exist, in the form of Federal subsidies, which promote such pollution. The major problem areas include:

A. All toxins from all sources, particularly from industrial, agricultural and street/urban runoff sources.

B. Changes in the amount and patterns of sediment flow, due to destruction and conversion of riverine wetland vegetation and hydrologic modifications.

C. Destruction of freshwater wetland/floodplain ecosystems as a consequence of Federal projects, the secondary impacts of such projects and agricultural clearing and drainage.

D. Ground water and surface water diversion, principally for irrigation, municipal and industrial water supply and perhaps, increasingly in the future, energy development.

E. Agriculture as a source of pollution through introduction of toxins and sediment, and clearing and drainage of wetlands.

F. Federally sponsored, funded and assisted programs--primarily Federal water resources development, but also federally assisted infrastructure programs and energy development.

Recent and on-going administrative actions and litigation have influenced the scope and direction of some Federal programs which affect marine fish species, Federal authority to protect those habitats generally does not extend inland of the territorial seas. Instead implementation of such recommendations is solely dependent on state action. Fishery management council recommendations on fresh water, as well as estuarine habitat protection are therefore apt to be valiant but unheeded exhortations, with little enforcement punch.

MAJOR CATEGORIES OF FRESH WATER FLOW DEGRADATION AFFECTING ESTUARIES

To evaluate the actual or potential impact of the Clean Water Act and other statutes which affect freshwater flows entering estuaries, it is appropriate to outline the major categories of degradation of such fresh water flows which can adversely affect estuaries. In general, the broad categories of degradation in freshwater flows entering estuaries involve the quantity and quality of those flows.

Changes in quantity include modification in total volumes, seasonal discharges, rates and timing of freshwater flows. Changes in quality are of two kinds. They include introduction of contaminants into surface or ground freshwaters in a manner, amount or rate such that they enter estuaries. Contaminants of particular concern include toxic synthetic organic compounds, heavy metals and pathogens and major alterations in fluxes of nutrients and sediments. Changes in quality also include reduction in the introduction of beneficial organic material, such as plant detritus in dissolved or particulate forms, in fresh waters entering estuaries resulting primarily from loss of riverine floodplain wetland vegetation. Thus, clearing, drainage, filling or dredging of riverine wetland habitat can degrade estuaries. In addition, since some estuarine fish species spawn in freshwater or depend on food originating in freshwater inflows to estuaries, physical destruction of riverine habitat can reduce the productivity of estuaries.[4]

The major categories of pollution of surface and ground freshwater inflows affecting estuaries are summarized in Table 1. This table also summarizes the activities which are the sources of this pollution, classifies these activities as point or non-point sources of pollution in Clean Water Act parlance and designates these sources as major or minor in terms of their inflows. Table 1 also lists existing Federal statutes which may control these sources and qualitatively ranks the enforcement potential of these statutes, as presently administered, in terms of abating the pollution source so as to protect estuaries. It is recognized that this table represents an over-simplification of the sources of estuarine degradation through changes in freshwater inflows and types of Federal programs which are designed to abate such pollution or which, on the other hand, contribute to it.

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[4] See, e.g., Livingston, R.J., Effects of Forestry Operations on Water Quality and Biota of the Apalachicola Bay System, Final Report to Florida Sea Grant College (1978), 400 pp.; Livingston, R.J., P.F. Sheridan, B.G. McLane, F.G. Lewis, III and G.G. Kobylinski, The Biota of the Apalachicola Bay System: Functional Relationships, Florida Department of Natural Resources Marine Research Laboratory, Number 6 (1977), pp. 75-100.

Table 1. Categorization of pollutant/pollution type, source activity and scope and effectiveness or regulatory/enforcement authority.

Pollutant or pollution type affecting freshwater inflows	Source Activity	Significance of source for downstream estuaries	CWA[a] point or non-point	Statutes	Enforcement[b] potential
A. Introduction of Contaminant					
1. BOD	municipal	major	point	CWA	9
	industrial	major	point	CWA	9
	street/urban runoff	major	non-point	CWA RCRA (Subtitle D)	2
2. Pathogens	municipal	major	point	CWA	9
	industrial	minor	point		9
	street/urban runoff	major	non-point		2
	agricultural	minor	non-point		2
3. Inorganic nutrients	municipal - surface water	major	point	CWA	4
	municipal - ground water		non-point	RCRA	
	industrial - surface	minor	point		5
	industrial - ground water		non-point		
	agricultural - surface and ground water	major	non-point		2

Table 1. (continued) page 2

Pollutant or pollution type affecting freshwater inflows	Source Activity	Significance of source for downstream estuaries	CWA[a] point or non-point	Statutes	Enforcement[b] potential
4. Heavy metals/ toxics	municipal - surface water	minor	point	CWA	3
	ground water		non-point	RCRA SDWA	4
	industrial - surface water	major	point	FIFRA	4
	industrial - ground water	unknown	non-point		5
	dredged and fill material	major	point		8
	agricultural		non-point		3
	street/urban runoff		non-point		1
5. Sediment	municipal - surface water	minor	point	CWA	8
	industrial - surface water	minor	point	Federal water resource development legislation and agricultural programs	8
	street/urban runoff	minor	non-point		2
	agricultural	major	non-point		1
	discharge of dredged or fill material	major	point		7

Table 1. (continued)

Pollutant or pollution type affecting freshwater inflows	Source Activity	Significance of source for downstream estuaries	CWA[a] point or non-point	Statutes	Enforcement[b] potential
5. Sediment (continued)	clearing of riverine wetland vegetation	major	point and non-point		3
	hydrologic modifications	major	point and non-point		2
B. Groundwater diversions - changes in volumes and timing of fresh groundwater inflows	Fed. water resource projects	major	non-point	Federal water resource development programs, Water resources planning Act, 42 U.S.C. §1962, NEPA, CWA (208)	1
	agriculture-irrigation	major	non-point		1
	municipal water supply and waste treatment	major	point and non-point		2

Table 1. (continued)

Pollutant or pollution type affecting freshwater inflows	Source Activity	Significance of source for downstream estuaries	CWA[a] point or non-point	Statutes	Enforcement[b] potential
C. Change in volume and timing of surface fresh water inflows	Fed. water resources projects	major	point and non-point	Federal water resource development, infrastructure, energy and agricultural programs, 1899 Act, CWA NEPA CZMA	1
	destruction of riverine wetland/plain vegetation through conversion	major	point and non-point		2
	non-Federal discharge of dredged or fill material-residential/commercial development	major	point		7
	other hydrologic modification including channelization, dams, levees, dikes	major	point and non-point		1
	agriculture irrigation	major	non-point		1
	municipal water supply	major	non-point		2

Table 1. (continued)

Pollutant or pollution type affecting freshwater inflows	Source Activity	Significance of source for downstream estuaries	CWA[a] point or non-point	Statutes	Enforcement[b] potential
D. Loss of riverine wetland/floodplain vegetation, including reduction in nutrient recycling, sedimentation, waste treatment, flood storage and fishery spawning and nursery habitat functions	residential development plan	major	point	CZMA 1899 Act CWA NEPA	7
	public infrastructures-highways and sewers	major	point		5
	Federal water resource development programs	major	point and non-point		1
	conversion to non-forested uses	major	point and non-point		2
	energy development	major	point and non-point		2

[a] "CWA" refers to the Clean Water Act, 33 U.S.C. §1251, 1376; "RCRA" to The Resources Conservation and Recovery Act, 42 U.S.C. §§6901-6987; SDWA to the Safe Drinking Water Act, 42 U.S.C. §§300f to 300j-9; FIFRA to the Federal Insecticide Fungicide and Rodenticide Act, as amended by the 1972 Federal Environmental [Pesticide Control Act, 7 U.S.C. §§135 and 136; NEPA, to the National Environmental] Act, 42 U.S.C. §4221; CZMA to The Coastal Zone Management Act, 16 U.S.C. §1451, as amended by the Coastal Zone Management Improvement Act of 1980; the 1899 Act to Section 10 of the 1899 Rivers and Harbors Act, 33 U.S.C. §403.

[b] Enforcement Potential is on a ranking of 1 to 10. 10 means that existing institutional arrangements can and do fully control the source and pollution problems.

these types and sources of pollution. For example, as far as toxins are concerned, several chlorinated hydrocarbon pesticides have been restricted in use by EPA.[5] EPA is in the process of developing effluent limitations for industrial discharges of toxins under Section 304 and 307 of the Clean Water Act, 33 U.S.C. SS 1314 and 1317[6] spurred on by legislation, and EPA has, belatedly, proposed and promulgated regulations designed to implement Subtitle C entitled "Hazardous Waste Management" of RCRA.[7] If and when all of these programs are in place, control of industrial and municipal sources of toxic pollutants should be greatly enhanced. In addition, through litigation, e.g., *NRDC v. Callaway*, 392 F. Supp. 685 (D.D.C. 1975); followed by Administrative action, including promulgation of regulations under Section 404 by the Corps of Engineers, 33 CFR Part 320-329 (now under revision), and more recently, *Avoyelles Sportsmen's League, Inc.*, et al., *v. Alexander*, et al., 473 F. Supp. 525 (W.D. La. 1979), tenative efforts are now underway to control conversion of riverine wetland forests to agricultural or other uses which destroy natural riverine overflow vegetation and hydrologic cycles.[8] However, these efforts are at best limited in geographic scope, primarily to western Louisiana, such that clearing and dredging of riverine bottomland hardwood wetland forests continue; scientists are only beginning to understand the impact of agricultural pesticides on downstream riverine and estuarine systems;[9] far too little is known about the impacts of changes of riverine hydrology and sedimentation patterns on estuaries; and Federal water resource development projects, now spurred on by coal export and energy development prospects, proceed apace. On the whole, litigation to halt such projects, primarily under NEPA, has met with only limited and, typically, only temporary success.

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[5] See *EDF v. EPA*, 489 F. 2d 1247 (D.C. Cir. 1973); W.A. Butler, "Federal Pesticide Law," *Federal Environmental Law*, Environmental Law, Environmental Law Institute, 1974, p. 1232.

[6] *Natural Resources Defense Council v. Train*, 519 F. 2d 287 (D.C. Cir. 1975); *Environmental Defense Fund. v. Train*, Civ. No. 75-0172 (D.D.C.) (settlement agreement, June 7, 1976); *Natural Resources Defense Council v. Agee*, Civ. No. 75-1267 (D.C.C.) (settlement agreement June 7, 1976).

[7] See, e.g., EPA Hazardous Waste and Consolidated Permit Regulations, 45 Fed. Reg. 33063-33588 (Monday, May 19, 1980); EPA, *Proposed Ground Water Protection Strategy*, Office of Drinking Water, (November 1980); Tripp and Jaffe, "Preventing Groundwater Pollution: Towards a Coordinated Strategy to Protect Critical Recharge Zones," 3 Harv. Env. L. Rev. (1979).

[8] For a discussion of legal handles to protect riverine overflow forests, see P.A. Parenteau and J.T.B. Tripp, "Federal Regulations: Handles, Effectiveness and Remedies, *"Transactions of the Forty-fifth North American Wildlife and Natural Resources Conference* (1980), pp. 392-401.

[9] For detailed discussion about the magnitude, scope and impact of agriculturally-related toxic pollutants, see C.J. Schmitt and P.V. Winger "Factors Controlling the Fate of Pesticides in Rural Watersheds of the Lower Mississippi: River Alluvial (1980), p. 354-375.

FEDERAL ECONOMIC PROGRAMS CONTRIBUTE TO ESTUARINE FRESHWATER INFLOW DEGRADATION

Aside from industrial and municipal toxin problems, as the above discussion points out, many of the problems contributing to degradation of the quantity and quality of freshwater flows to estuaries are a direct or indirect result of Federal economic programs--direct appropriations, tax incentives and economic regulation. Thus while Federal regulatory programs, such as 404 may be working to maintain the quality and quantity of freshwater inflows, Federal water resources development and other economic programs still contribute to the degradation of those resources.

Federal funds for navigation, irrigation, flood control, water supply and hydroelectric projects directly subsidize modifications of riverine systems in a manner which typically affects estuaries. Federal subsidies in the form of tax incentives, agricultural flood control, SCS engineering assistance, price supports and other U.S. Department of Agriculture programs to promote the clearing and drainage of coastal flood plain wetland forests and their conversion to cropland or other non-forested uses.[10] A combination of Federal irrigation projects, particularly in the arid West and Southwest, and Federal controls on energy prices promote wasteful use of fresh water for agriculture, with contaminant downstream effects on estuaries. Federal infrastructure investments, such as those for highways and sewers, still support development in riverine flood plains. Finally, Federal economic regulations of railroads increases the cost of rail transportation relative to barge transportation and thus increases the "demand" for Federal navigation projects, although the Staggers Rail Reform Act of 1980 (P.L. 96448) over time should begin to rectify this inequity.

IDENTIFICATION OF ALTERNATIVE STRATEGIES FOR ACHIEVING ECONOMIC OBJECTIVES WHILE MAINTAINING FRESHWATER INFLOWS TO ESTUARIES

Because Federal economic programs and policies play such a crucial role in activities which alter adversely freshwater flows to estuaries, reformation of those policies is the single most important factor in any national strategy to protect estuarine resources through proper management of the quality and quantity of freshwater inflows. Judicial strengthening of private and public nuisance concepts to provide for strict liability for private polluters whose waste streams to ground or surface waters degrade estuaries is another important factor in such a strategy.

Continued degradation of the Nation's renewable resource base which supports its fisheries and shellfisheries should be deemed unacceptable in terms of national and global trends for such resources.[11] If this objective is to be attained, primary reliance on Federal or state regulatory programs is only a partial answer. The larger quest must be the search for alternative pathways to achieve economic objectives which avoid disruption of surface and groundwater systems in a manner which will maintain estuarine resources. In many cases, because of the perverse impact of Federal economic policies, alternative conservation-oriented water supply, energy and transportation investments not only avoid such disruptions but enjoy substantial economic benefits vis-a-vis disruptive programs.[12] In addition, insofar as conversion of riverine forests to agricultural use is expanded, other Federal policies which promote conversion of farmland to other non-agricultural uses should be altered.[13] Finally, economic incentives to support development of innovative technologies which will preserve riverine and estuarine renewable resources must be identified and adopted. Federal natural resource agencies, such as the Department of the Interior, the National Marine Fisheries Service and Environmental Protection Agency should participate in the effort to identify and implement such alternatives.

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[10] For a comprehensive discussion of Federal subsidies in support of the conversion of bottomland hardwood wetlands to agricultural use, see L. Shabman, "Economic Incentives for Bottomland Conversion: The Role of Public Policy and Programs," Transactions of the Forty-Fifth North American Wildlife and Natural Resources Conference (1980), pp. 402-412.

[11] See The Global 2000 Report to

DISCUSSION

QUESTION: Gil Redonski, Sport Fishing Institute. Mr. Tripp, I'd like to ask you what the status of the Rural Clean Water Act is? You mentioned non-point source pollution from agriculture, and that the Rural Clean Water Act would deal with the problem of non-structural pollution abatement. One of the problems is that, as I understand it, it has not been funded. Can you give us any insight on the future of the Rural Clean Water Act?

REPLY: Only to a very limited degree. I'm not terribly familiar with the program, but I think you mentioned one of the problems which is funding. If you don't have funding, and unless you have a constituency that is interested in doing something about the problem in certain basins, the problems of erosion become virtually so severe that you might want to develop a constituency among the farmers to do something. The other major problem is that all these U.S. Department of Agriculture programs are voluntary. There is no conservation service, even where they provide subsidies to farmers to enter

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the President, Entering the Twenty-First Century, Volume One, Council on Environmental Quality (1980).

[12] For economic analysis of alternative investments, see, e.g., Z. Willey et al., An Alternative to the Allen-Warner Valley Energy System: A Technical and Economic Analysis. EDF (July 1980); J.R. Morris and C.V. Jones, Water for Denver: An Analysis of Alternatives, EDF (1980); affidavits of Dr. Granville Sewall and Dr. Clifford Russell in support of motion for an injunction, EDF et al. v. Johnson, Civil Action No. 79-2228 (S.D.N.Y. 1979).

[13] The rate of and courses of conversion of the Nation's agricultural land base to non-agricultural uses are presently under study by the National Agricultural Lands Study, CEQ and the U.S. Department

enforceable contracts with the farmers about how they should change their practices to reduce sediment discharges, pesticide discharges or clearing. It is a voluntary program, and by and large, a lot of them have a very short discount period. Of course, a lot of farmers are tenant farmers and are on year to year leases. They are not interested in spending any money to try and take care of these problems. But in a lot of cases, you are talking about investments that may not have a pay-off for ten years, and there just aren't a lot of farmers that want to wait that long, and the agencies aren't making them do it.

QUESTION: Is the lack of technical data slowing down some of the litigative initiatives that you know about?

REPLY: I think that is a problem. There is a tremendous amount of technical data. I can think of two examples: One is the effect of changes in the use of riverine flood plains on riverine hydrology and therefore, estuarine hydrology. You are talking about using some really sophisticated state-of-the-art models to try and predict what is going on and it is difficult to do. It becomes particularly difficult when one is dealing with a large number of cumulative effects. I know that the Corps, in the case of the Cache River Basin said that project would have an insignificant effect on the levels of water on the White River. The Yazoo River Basin proposed pump project raised a question and comments on some draft EIS, as to how that would affect flood stages in the Mississippi. The response was that it would raise flood stages in the Mississippi by one foot at Vicksburg which struck me as being quite a bit, but they said downstream it would just disappear. I find that hard to believe, but it is very hard to find technical data to show response to that. Another example would be changes in inputs of organic nutrients resulting from the destruction of wetlands. It is just literally impossible to get any information on that because reductions on the amount of organic nutrients which are of value to the river and the estuary are not reflected in the water quality standards. Water quality standards deal with BOD, or toxics. Introduction of contaminants or removal of something is a legal problem but also it is a serious technical problem.

I think, when you talk about hydrology, you get into the driving forces behind the systems. That is a new and different world, the process side of the ecosystem rather than the structual side. I know a few years back I was working on an EIS for a highway crossing some wetlands on Long Island. In the mitigation recommendations, we suggested they fix up a few wetlands, but we also suggested that they open up some of the culverts and improve the water flow a little bit so as to improve the energy flux and other processes in the wetlands.

That got down to Washington and it got a lot of interest from the folks in the Department of Transportation environmental review session because they thought it was really innovative and different to be trying to mitigate by adjusting the processes rather than just the structure of the system. I think that gets us into a very complicated world

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of Agriculture. The Study is expected to make recommendations on changes in Federal program and policies which support such conversion.

but I think it is one we are going to have to step into fairly soon, because you have these driving forces working on your ecosystem and what we are really driving at a lot of times is controlling them. Yet we are so used to buying pieces of wetland or building islands for mitigation, that we often loose track of the fact that what we are really after is trying to conserve the process base.

Most of the agencies that may be concerned about this whole problem tend not to appoint hydrologists, or very few of them. The agencies that are interested in engineering manipulation of the river and estuaries, and there are a large number of them, have hydrologists who don't have training in ecology. This doesn't seem to enter into their thinking.

QUESTION: John Clark: I'd like to ask just one more question here before we move on to the next speaker. I would like to ask Jim what benefit he would see in the work he does from far more extensive quantitative, monetary evaluation of the resources that are dependent on estuaries. Is that going to help or hurt your case?

REPLY: Tripp. My answer is that economic quantitative analysis of the value of the Nation's natural resource base should be pursued with vigor. I think you have to be acutely aware of the limitations of these studies. You also have to remember that the level of sophistication of economic analyses done to justify water resource projects is also in an infantile state. Most of the time, we can take any Corps project, I won't speak for the Water and Power Resources Agency because I haven't done any work with it, and easily find highly qualified economists who will go out and say it is an absurd methodology that the Corps uses and very overstated. A large economic analysis is a tool and nothing but a tool, carried out by various groups to further a political fight. Even recognzing the severe limitations of quantitative economic analyses, I think that they should be carried on. I got a paper just the other day from an economist on the value of wetlands. His argument was that the degree of sophistication of analyzing the value of wetlands from the quantitative point of view is still in a very primitive stage, and that the major economic argument in support of preserving wetlands is uncertain, i.e., the risks that you take by destroying the resource.

CLARK: I have some doubts whether the answer you get every time is all that helpful to you because I've seen some analyses of the values of components of estuaries expressed in dollar terms funded with state-of-the-art analysis. In fact, it seemed like a rather trivial price tag per acre of wetland or per acre of estuary, and I'm not so sure that in every case the price tag we come up with is going to give us the answer we want.

WATER MANAGEMENT ON THE COLUMBIA RIVER

David Kent

Columbia River Basin Commission, Portland, Oregon

We have heard comments about needing long term studies of estuaries twenty-five years from now. How do we deal with Federal water resource projects when we lack adequate information from which to base decisions. Jim addressed these issues more from a national perspective. I would like to speak about the regional problems on the Columbia River.

The Columbia River with its estuary and its tributaries is the dominant Pacific Northwest water resources system. Originating at Columbia Lake in the Canadian Rockies, the Columbia flows about 1200 miles to the Pacific Ocean. Discharges on an annual average are about a quarter of a million cubic feet per second of water at its mouth. The drainage area is about 260,000 square miles or about five times the drainage area of the Chesapeake system. This 260,000 square miles includes about 85 percent of the total area of the Pacific Northwest. The Columbia system, including its largest tributary the Snake River, flows through seven states as well as Canada. The Columbia River estuary, which for administrative purposes is defined as the last 46 miles of the river, is the ninth largest in the United States. Here fresh and salt waters mix in a rich and fragile environment. The region's water problems stem largely from the competing uses to which the river is put. Residents of the Pacific Northwest count on the river to supply sufficient hydroelectric power and support ever-increasing agricultural production with irrigation development. We count on it to provide transportation for commerce while maintaining fishery resources and to provide recreation opportunities for everyone. What we are asking is that the Columbia be all things to all people all the time. Unfortunately, what we are asking is not possible all of the time. To help understand the puzzle of these competing uses, I am going to briefly describe just three of the major areas for concern. Presently, the Columbia River with its storage system is used to generate about 80 percent of the electrical energy for the northwest. To supply this energy, the river's water must pass through turbines in one or more of the 60 mainstream or tributary generating plants. These turbines threaten the survival of juvenile fish moving downstream, while the dams present an obstacle to adult fish migrating upstream.

As the human population of the region increases, so too will the demand for energy. Because most of the best hydroelectric sites already have been dammed, it will be necessary to build more thermal or nuclear-generating plants which divert water for cooling purposes and much of this water then is lost. Approximately eight million acres of land in the Pacific Northwest are now being irrigated by water diverted from the Columbia River system. This accounts for more than 90 percent of the region's total water diversion and comsumptive use. It is expected that within 20 years, there will be a 25 to 40 percent increase in irrigated land within this region. Already competition between the hydroelectric generation and irrigation is intense. The amount of hydroelectricity generated depends on the volume of water passed through a given generating facility. Reduction in volume means less potential for electric generation, not only at the first structure but at each of the dams that are downstream. In other words, the loss is multiplied by the number of dams downstream of the diversion site. Furthermore, electricity is used to pump the water inland for irrigation, thus placing additional demands on existing generating capacity. Meanwhile, hydropower and irrigation demands are putting pressure on a third use of the Columbia's waters, the fish runs.

For maintaining fish runs, water must be available in adequate quantity and quality for the fish to survive and at the proper time to provide for both the upstream and downstream passage of the juvenile fish, the amount of water available to generate electricity is reduced and you can see that all of these are interrelated and tend to compound each other. Power generation, irrigated agriculture, anadromous fish runs are all vital to the Pacific Northwest region but, in varying degrees, are at odds with each other. It is clearly evident that the development of any one of these uses to their full potential can only be at the expense of others. Already you can see how difficult these conflicts are to settle, and I have not even mentioned instream flow needs for navigation, recreation, water quality protection, and preservation of the natural environment. And there are others.

But, competing uses are only half the problem. The other side of the puzzle is that of jurisdiction. The Columbia River system waters within the United States are controlled by seven states, at least nine Federal agencies, several state organizations, and a multitude of public entities, local jurisdictions, and under permit, private individuals. Each of these entities has only limited authority over the responsibility for the management of the Columbia's water. Its flow is stored or diverted and consumed as a result of numerous decisions that are usually uncoordinated and made with little regard for other demands. The river's management is influenced by citizens' groups, municipalities, users from other states, local Indian tribes, and a host of these entities involved has overall or even broad responsibility for the uses of the Columbia River water. All too often, the result is a variety of piecemeal and conflicting policies that fall short of everyone's desire for wise management of the river. So, having explained that there are competing uses and numerous jurisdictions involved in water resource decisions before the water reaches the estuary, we can now address the question of how choices are made, or to put it another way, who gets what and why and how these impact the Columbia River estuary.

It would be naive to suggest the water allocation decisions are based on what is best for all. Money influences decisions and managing the Columbia River is no different. Those uses which are economically most profitable, are the ones which receive the greatest consideration by the decisionmakers. In the case of the Columbia, hydropower is the most important. Irrigation is next, followed by transportation, and a distant fourth or even further, would come fisheries and conservation. Let's examine this decision hierarchy in terms of its economics. What are the values of the various uses? I had some trouble digging up money figures for some of these, so I am going to have to improvise in some of the cases. First, let's look at electricity. As I mentioned earlier, hydropower presently provides about 80 percent of the region's energy. Most of the remaining 20 percent is generated at thermal electric or nuclear plants. As a power resource, the Columbia River system has more hydropower potential than any other system in America; about one-third of the national total. There are now over 24½ million kilowatts of installed capacity and another 5½ million under construction, for a total of 30 million kilowatts. Except for some small projects, that is probably close to the river's short term potential. That hydropower energy represents about 50 percent of the energy generated in the Pacific Northwest. I do not think I need to translate that into dollars and cents. It is enough to say that the hydroelectricity generated on the Columbia River is big business. There are not many northwest residents who would want to see it otherwise since they are all well aware that they pay considerably less than the rest of the country for their electric energy. The magnitude of the dollar decisions involved warp the conservation and fisheries concerns of those who depend on the estuary and its resources. Let me add that it has been estimated that in the next two decades, the population of the Pacific Northwest region will jump from its present seven million people to more than eleven million. The demand for energy can be expected to increase.

Along side the increased demand for hydropower will be the increased demand for water to irrigate farmlands, to produce more food and fiber for domestic use and export. The Corps of Engineers has estimated that our needs in the northwest for irrigated land may increase by four million acres over the next fifty years. New irrigation development has been increasing in recent years at a rate of about 80,000 acres per year. The projected increase of four million acres will deplete the Columbia River by nearly nine million acre-feet of water. That translates to more than 966 megawatts of potential power and more than 1.8 billion dollars in economic revenue annually. My rough calculations indicate that in 1972, the value of the seven highest-ranked crops in the Pacific Northwest was about 1.5 billion dollars annually. Taking the percentage of those crops that are irrigated, I found their worth to be 930 million dollars annually. Had I included wheat, of which only five percent is irrigated, I would have found a total worth of over a billion dollars. In other words, except for wheat, almost 90 percent of the income in the region from the seven more prolific crops is a direct result of irrigation. Perhaps, I need to clarify something for those of you who are not familiar with the Pacific Northwest. Except for the area west of the Cascade Range, most of the region has a fairly dry climate. Of the whole, only a small percentage is the lush green of the Willamette Valley or the rain forest of Northwest Washington.

Most irrigation in the northwest is powered by electricity. There are some who irrigate by gravity feed systems, but the majority use sprinkler systems or other systems that require electricity to pump the water. So not only is irrigation reducing the potential for energy generation by withdrawing water, it is also a tremendous consumer of electricity. This energy, that is lost, plus the necessary power to run the irrigation pumps, when valued at the replacement costs of the additional generation facilities that must be developed, results in a continuous and increasing expense to power consumers in the northwest as irrigation grows.

As I said earlier, the next use of the river, in terms of economics, would be transportation. Recent dollar figures are not available. Tonnages shipped are used as a measure of water-borne commerce significance. In 1975, nearly 65 million tons of commerce were moved through the Columbia River system. This total comprised approximately 17 million tons of foreign imports and exports and 44 million tons of internal and local movement. The system provides a principal waterborne outlet for a large portion of Oregon, Washington, and Idaho crops. Export grains and shipment of forest products are among the principal outbound items of commerce. Much of the petroleum products used in the area are brought into the Columbia by deep draft tankers and then are distributed by barge and truck into the interior. Fortunately, navigation on the river does not conflict with many other uses. Dams are built with locks, and water volumes for their operation are usually less than is needed for the fisheries. There was no question as to whether the money should be spent to dredge the Columbia River channel after the May 18 eruption of Mt. St. Helens. Millions of dollars to the region are lost every day that the navigation channel was closed. By the way, I believe the recent cost figure for that total dredging project was around 53 million dollars.

In a distant fourth come the fisheries and the estuary. Currently, the value of the fisheries to the region is about 20 million dollars. Obviously, that is pretty small when compared to the value of hydropower, irrigation, or transportation. It is this disparity in value that is the base of the issue of water use priorities. Fish require adequate flows and assistance to negotiate dams and other water intakes. This water represents potential economic losses to other uses and the monetary returns from the fish do not amount to much regionally. Here is a quote from a big energy official in the northwest that I think captures the essence of the issue: "If the amount of water that must be spilled is as large as some fish interests request, the loss of energy could be substantial and possibly disproportionate to the value of the additional adult salmon that will return to the Columbia as a result." What he is saying, I gather, is that money is the scale on which we should weigh the worth of protecting the fisheries. I think that is a point that could well be argued. Having determined that economic reasoning seems to be carrying the greatest weight in decision priorities between the river's competing uses, I would suggest that social concerns would follow, and finally, environmental protection.

Obviously all of the current uses of the Columbia River are of value to the region. I am in no way saying that any one of them should be precluded. But, I am sounding a warning that must not be ignored. On the Columbia River, the water volume is rapidly approaching, if not already passed, the point of over allocation, and a viable management structure has not yet surfaced. The implications of over allocation to the estuary and the river's natural systems is profound. Only now through the Columbia River Estuary Data Development Program and other research programs on the Columbia is the first piece of that puzzle called the Columbia River being studied systematically. Let us hope that the solution of this puzzle is found before it is too late for us to control changes in the way the Columbia River is managed.

DISCUSSION

QUESTION: I would like to ask whether you think that, with an increase from seven to eleven million people, how much of the apparent increase in energy supply needs can be taken care of by conservation rather than production of more power:

REPLY: KENT; I haven't seen any figures on how much of that increase of energy consumption could be met by conservation. Some of the figures that have been tossed around have been as high as 50 percent. But as far as the northwest is concerned, I don't know. It is a fact, for what it is worth, that the northwest region has historically had very cheap electrical energy. It may very well be that shifting to alternative sources of energy could result in meeting most of these demands.

Along the same lines, I read recently in Business Week that the per capita consumption of electricity in the northwest is twice the level of consumption of the rest of the country and that would certainly suggest to me that the 50 percent figure is not far off.

FRESHWATER INFLOW AND WATER MANAGEMENT IN CALIFORNIA

Gerald Johns

California State Water Resources Control Board
Sacramento, California

I would like to present a brief example of how California has tried to handle its water supply problems and how it tried to merge technical, legal information, legal principles and public interest in order to develop enforceable water quality standards to protect the San Francisco Bay-Delta system. What this requires is adequate inflow to the estuary in order to protect that system. The delta represents about half of the fishery in California which either migrates through or lives in the delta, specifically, or in the bay area. In order to give you an idea of what we are talking about here, I have a few slides which show California and some of its water supply projects. Most of California's water supply falls in the northern part of California above the delta. However, about two-thirds of its population is below the delta and, in addition, water supplies to the San Joaquin Valley are provided not only from the San Joaquin River but also from the Sacramento River. An engineer once said that the problems in California are not water supply problems. There is plenty of water in California. What exists is a water distribution problem, because all the water is in the north and all the uses are in the south. So, one of the issues then is that the delta sits basically at the hub or the center of this water distribution problem. When water supply and water distribution questions are raised, you always have the corollary issue raised with protection of in-basin users and the instream uses. We have the same problem in California as in the other basins in the Nation where their interests are all competing for the same block of water. We have in-basin users not only within the San Joaquin Valley and the upper Sacramento Valley that use the water there for agriculture and industrial supplies, but there are users in the delta that need water for salinity control, flow for fish protection and also a large exporting interest that takes water out of the delta, down the California aqueduct into southern California, and through the Delta-Mendota Canal into the San Joaquin River. Each of these interests, of course, questions the legimate needs of each in terms of whether or not their needs are legitimate. In order to adopt enforceable standards, you basically have to convince each other--all these competing interests --that each of their needs are legitimate. In other words, goals and priorities for water development and water distribution must be established.

Also you need to be able to document technically how you are going to achieve these goals. When California recently adopted a Water Rights Decision in 1978 and a water control plan to address the issues of protection for the delta, somebody needs to do the balancing. We have competing interests, and somebody has to step in and do an independent balancing act. That is basically what the agency that I work for does. The State Water Resources Control Board is the water-right agency in California. People that divert water in California have to apply to our agency for an appropriate permit and we then set terms and conditions for those permits. In the delta they take the form of water quality standards and export limitations.

We are also in charge of water quality laws in California. We implement not only California water quality laws, but also the Federal Clean Water Act. The board has five-members. Each member is appointed by the governor to a four-year term. In water right proceedings, which are quasi-judicial in nature, you have cross examination of witnesses and the board acts more or less as the judge. In Decision 1485, we had 32 very arduous days of testimony presented where we had no fewer than 35 participating groups each cross examining each other. It took over two years to accomplish. It is not the type of project you want to do very often, to say the least. In the delta, there are a number of agricultural uses on a number of islands that are created by the water entering through the delta. There are municipal and industrial uses within the delta. Pittsburg and Antioch also divert water for use within the delta and outside of the delta. There are interests that divert water from the center portion of the delta, interests that must manage the productive Suisun Marsh area, interests that manage delta fisheries, and that's all. But that is enough, because we are all looking for the same types of things. So when we hold hearings, we basically invite parties to come together, present the information, and then we try to sort out the facts. The information is presented to us by U.S. Water and Power Resources Service, the U.S. Fish and Wildlife Service, the California Department of Fish and Game and the California Department of Water Resources in the four-agency ecological program. The program has been collecting data in the estuaries since 1959 and probably has the best continuing record of fishery related impacts that exist.

The history of water development in California is too great to go into here. I think it will suffice to say that the problems have been around since the early 1900's. Water projects were built in 1945 and later supplied water in California for inter-basin transfer. It has been a boiling controversy ever since. The things that I might mention rather quickly are the fact that we have some laws on the books that help guide how we should develop standards. The Delta Protection Act was adopted in the 1950's and was labeled at the time as being the great law that would tell everybody exactly how much the delta should get or what it is entitled to but not how to provide the water. It becomes an administrative problem to try to provide the water.

In 1976, we started our delta hearings and we were basically working from a very set stage. We had already issued water right permits for the Central Valley Project and State Water Project. In these permits, we have a rather nice clause that the Federal Government is not too crazy about. Basically this is the reserve jurisdication. What we do is we recognize at the outset that we do not know everything there is to know. We adopt standards based on the imperfect knowledge at all times. We, however, reserve the jurisdiction to change those standards later on. This does nothing but create havoc with water-development engineers because they calculate their yields based on what the standards are currently, and then the standards change in 10 to 15 years. So they are continually trying to figure out what is going to be the next set of standards. This is a thorny issue between the Federal Government and the State. We have also adopted water quality control plans for the Central Valley and the delta under our Clean Water Act authorities. Here we had some legal guidance, but we did not have a clear set of principles that should be followed. We also were in the process of having or experiencing a very extensive drought in California and everybody was clamoring for the same block of water. It didn't take very long before we had what I called an "ah ha" experience. You sit down and you go "ah ha," that's what the problem is.

Our first major discovery was that if there was an easy political answer to the problems of water supply in California they would have thought of it 50 years ago. There was simply no easy way out of the problem. First, you are not going to please everybody, so whatever decision you come up with it is going to have to be legally and technically defensible because you are likely to be sued no matter what you do. First, take the problem apart, then divide it into bite size pieces and then start chewing away on the pieces. The other thing we had to do was to recognize that we were not going to solve all the problems all at once. You have concerns with basin development and export development and we had to pick out those that were most important and try to resolve them. Who should protect the delta was the first issue we were faced with? Was it the in-basin users who are diverting water within the basin or the exporters? There are many types of exporters in California.

In addition, you have the rather large State Water Project and the Central Valley Project which are delivering water to the San Joaquin Valley in Southern California. The water law in California states that exporters are the last to be considered in the system regardless of the kind of priority or the way the development projects were built. The State Water Project and the Central Valley Project were the last of the exporters. I will give you a brief example of how we applied this concept in California. First of all, we had to develop a rational policy of what protection should be afforded fisheries. In this case, I will give an example of striped bass survival. Luckily, we had a rather large amount of data on striped bass. The information indicated that flow and diversion rates out of the delta affected striped bass survival, particularly young striped bass. We determined that had the project not been built, there would have been a stiped bass index of around 71. A striped bass index is a relative number that indicates the relative abundance of young fish in the estuary. With those same relationships, we determined that the existing plans that we had at the time would have provided an index of around 63. We then went about developing standards that would try to achieve this index 63 goal at the mitigation level in the estuary. In the standards that we developed, we require much greater protection in wet years than would have been experienced historically and we tried to allow for lesser protection in critical dry years. Yet, we still try to get the overall protection needed to attain this mitigation level. In addition, we have some long-term goals of trying to reach what is called "recent historical levels." These provide a much higher protection and include some major enhancement. We feel this can only be achieved with the removal of the exports out of the southern portion of the delta where they are currently damaging the estuary. There are current proposals to do that.

In summary, I would like to emphasize that we all know that estuaries have very difficult problems that are hard to solve. They must be solved by taking the problems apart, developing goals on which to base standards, and having the technical information available to back up those goals. The program must then be developed to attain a suitable solution. The other key ingredient is to have an agency with the authority that can implement the standards. The agency must actually implement the program. Decisionmakers need the scientific information that we will be talking about here, but it is fairly worthless if we do not have the guidance in terms of what the public interest is. In closing, I would like to say that in the developing centers of California we realized at the outset that we could not make everybody happy. We have 14 lawsuits being sued by in-basin users, by exporters, and by people within the delta. We actually welcome these suits because we are developing new ground here; and we hope that these lawsuits will help resolve the long standing legal principles and questions of authority that have plagued us in the past. We were not successful in making everybody happy, however, we were successful in our secondary goal, and that was to make everybody equally unhappy.

FRESHWATER INFLOW PLANNING IN TEXAS

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The Texas bays and estuaries are valuable public resources. They provide habitat for fish, birds, and other living organisms; they contain important archaeological and historic sites; and they are scenic and recreational assets. In addition, the bays and estuaries attract and support business and human uses; for example they have been modified to provide shipping lanes for Texas' marine commerce, and are used for recreation by thousands of visitors annually.

Texas has almost 400 miles of shoreline with the Gulf of Mexico, most of which is bordered by narrow strips of sand or barrier islands. Behind the islands are located seven major estuarine systems and several smaller estuarine areas. They are fed by eleven major rivers, ten with headwaters originating within the State. These range from the high precipitation drainage basins of the northeast Texas coast to the arid drainage basins of the southwest Texas coast. Associated with these drainage basins are approximately 2,100 square miles of coastal environments, including more than 1.5 million acres of open-water bay surface area and approximately 1.1 million acres of adjacent marshlands and tidal flats.

Texas' estuaries are a source of significant quantities of inputs to the State's economy in the form of navigational networks, a natural source of treatment for nutritive wastes, mineral and energy deposits, fisheries, and recreation areas. For example, the total Texas harvest of estuarine-dependent seafoods by commercial and sport fishermen averaged about 110 million pounds per year during the 5-year interval from 1972 to 1976 (i.e., ∿ 20 million lbs/year of fish and ∿ 90 million lbs/year of shellfish). Shipping lanes traverse the entire Texas coastal area, linking Texas' 33 ports, including the Brownsville Corpus Christi-Houston-Galveston-Beaumont-Port Arthur energy refining and petrochemical production and shipping complexes to world and national markets.

Significant proportions of the crude oil and natural gas produced in Texas and sold into national markets are produced in the Texas coastal area and off-shore of the coast. The Texas coastal area also supports major agricultural enterprises ranging from tropical fruits and vegetables to food grains, livestock, and timber. The Texas coastal area has five Standard Metropolitan Statistical Areas (SMSA) in which about 3.8 million people or nearly 30 percent of the population of Texas live and work in a highly specialized, technologically advanced industrial society. These SMSAs are linked to the Texas interior through transportation and trade and are located near the mouths of rivers which are used throughout their extent as sources of fresh water for municipal, industrial, agricultural, mining, hydroelectric power, navigation, recreation, and other purposes, including disposal of treated waste effluent. All of these factors must be taken into account, as the topic of freshwater inflow for bays and estuaries is considered.

Since practically all (97.5%) of the coastal fishery species are considered estuarine-dependent, and since the esturies themselves are dependent upon freshwater inflows for nutrients, sediments, and a viable salinity gradient, the occurrence of sufficient freshwater inflow is necessary to maintain the productivity of Texas estuaries.

Enactment of Senate Bill 1139 by the 65th Texas Legislature (1977) resulted in the consolidation of the three former Texas water agencies; the Texas Water Development Board (TWDB), the Texas Water Quality Board (TWQB), and the Texas Water Rights Commission (TWRC). In so doing, Senate Bill 1139 created a new Texas Department of Water Resources (TDWR) with a newly-created Texas Water Commission (TWC) as its judicial arm, and the existing six-member gubernatorially-appointed and Senate confirmed Water Development Board incorporated as TDWR's policy branch. All executive and administrative functions of TDWR are the responsibility of the executive director, who is employed by the board. The executive director also assumes the mandates for development of and periodic updating and amending, as necessary, a Texas Water Plan and completion of comprehensive studies to determine freshwater inflow needs of Texas bays and estuaries. The TDWR is charged with the responsibility of ensuring that all present and future water needs of the State are met through an orderly water development and management program.

The substantive law of Texas with regard to water development, water quality, and water rights was not altered by consolidation of the water agencies. However, under TDWR an increasingly effective coordination of water quantity and water quality programs is being realized since problems and solutions associated with both aspects of water resources management are now within the sphere of a single water resources agency.

State law directs the executive director to "prepare, develop, and formulate a comprehensive state water plan," wherein the director must "also give consideration in the plan to the effect of upstream development on the bays, estuaries, and arms of the Gulf of Mexico and to the effect of the plan on navigation" (Section 16.051, Texas Water Code). Codified from the Texas Water Development Board Act of 1957, these statute provisions were the first legislative directives to focus Texas water resources planning on the real problems associated with alteration and/or depletion of riverine flows to the estuaries.

As a result of the Legislature's 1957 planning mandate, a Texas Water Plan was prepared, published, and released in 1968. Following an affirmative finding by the Texas Water Rights Commission that the plan gave adequate consideration to the protection of existing water rights, the plan was formally adopted by the Texas Water Development Board in 1969. In addition to describing the State's water resources, projected requirements, and a proposed plan of development for each of the river basins in the State, the plan also provided for the delivery of up to 2.5 million acre-feet per year of supplemental freshwater inflow to Texas estuaries between Galveston and Corpus Christi through controlled releases from the coastal component of the proposed Texas Water System. Conceptually, the system was to conserve and control water from basins of surplus to areas of need throughout the State. Although the Texas Water Plan tentatively provided for supplemental freshwater inflow on an annual basis, it was clearly recognized that the quantity specified was a preliminary estimate based on the best available information at the time. Furthermore, the optimum seasonal and spatial distribution of these proposed supplemental inflows could not be determined at that time because of insufficient ecological knowledge concerning these large-scale ecosystems and their interlocking components.

The acute need for comprehensive estuarine data bases and reliable set of technical criteria for defining the responses of the ecosystems to variable freshwater inflow regimes was obvious in order to analytically solve the problem. Although several limited programs were underway, they were largely independent of one another and none of the programs were truly comprehensive. In fact, in some Texas estuaries virtually no data had been collected. Therefore, the Texas Water Development Board, in cooperation with the U.S. Geological Survey, initiated a reconnaissance-level study program during 1967. This Bays and Estuaries Program was progressively expanded through the following years, particularly after the additional legislative recognition and funding provided through enactment of Senate Bill 137 by the 64th Texas Legislature in 1975. Under the mandate of this State law, the executive director of the department must "carry out comprehensive studies of the effects of freshwater inflows upon the bays and estuaries of Texas, which studies shall include the development of methods of providing and maintaining the ecological environment thereof suitable to their living marine resources" (Section 16.058, Texas Water Code). Senate Bill 137 also amended State public policy, declaring "it is the public policy of the state to provide for the conservation and development of the state's natural resources, including ...the maintenance of a proper ecological environment of the bays and estuaries of Texas and the health of related living marine resources" (Section 1.003, Texas Water Code). Further, the law directs "in its consideration of an application for a permit to store, take, or divert water, the [Texas Water] commission shall assess the effects, if any, of the issuance of the permit on the bays and estuaries of Texas" (Section 11.147, Texas Water Code).

The principal problems that have affected this assessment stem from the previously incomplete analysis of the freshwater inflow needs of Texas estuaries, and from the fact that the adjudication of surface water rights for each Texas river basin is a complex and extremely lengthy legal procedure. Required by the Texas Water Rights Adjudication Act of 1967 (Section 11.301, Texas Water Code), the adjudication process was established to assure each surface water claimant all of the due process and constitutional protection to which each is entitled, and to provide for the "administration of water rights to the end that the surface water resources of the state may be put to their greatest beneficial use" (Section 11.302, Texas Water Code). As of August 31, 1980 the adjudication program was about 72 percent complete (5,989 parties adjudicated of a total 8,336 parties statewide). Although the process has been accelerated in recent years, it may still be several years before adjudication of claims in all Texas river basins is completed. Currently, several final judgments have been rendered by appropriate State district courts and certificates of adjudication have been issued by the Texas Water Commission for portions of the Rio Grande, Colorado, and San Antonio river basins.

In considering each application for a permit for the appropriation of State water, the Texas Water Commission is directed to "assess the effects, if any, of the issuance of such permit upon the bays and estuaries of Texas" (Texas Water Code, Section 11.147, as amended). Thus, a water rights permit may be denied for any valid reason, including detrimental effects on the bays and estuaries. Similarly, in developing the State water plan, the TDWR is directed to "give consideration in the plan to the effect of upstream development on the bays, estuaries, and arms of the Gulf of Mexico..." (Texas Water Code, Section 16.051, as amended). The commission must make decisions on each application for a permit, which could have a significant effect upon an estuarine system, using the best available information on existing unappropriated water and relying upon recommendations or information provided by the executive director, other State agencies such as the Texas Parks and Wildlife Department, as well as any testimony which may be presented at the public hearing on each such application.

State law (Section 11.024, Texas Water Code) directs the commission to give preference to applications in the following priority order: (1) domestic and municipal uses, (2) industrial uses (includes commercial fish production or aquaculture), (3) irrigation of agricultural lands, (4) mining and recovery of minerals, (5) hydroelectric power, (6) navigation, (7) recreation and pleasure, and (8) other beneficial uses (includes stockraising, public parks, and game preserves). Further, the commission is to give preference "to applications which will effectuate the maximum utilization of water and are calculated to prevent the escape of water without contribution to a beneficial public service" (Section 11.123, Texas Water Code). When there are conflicts between appropriators of State surface water the law directs that "the first in time is the first in right" (Section 11.027, Texas Water Code), except that "any appropriation made after May 17, 1931, for any purpose other than domestic or municipal use is subject to the right of any city or town to make further appropriations of the water for domestic or municipal use without paying for the water" (Section 11.028, Texas Water Code).

Since all surface waters of Texas are the property of the State, and since the responsibility for allocation of surface waters among appropriators and competing uses in Texas rests with the Texas Water Commission pursuant to State law, it is crucial to understand that the official identification of estuarine freshwater inflow needs, the allocation and possible direct appropriation of State water to meet these needs, and the equitable adjudication of water rights and claims are deeply intertwined. Further, this fact must be recognized by all involved in the definition and resolution of this coastal issue.

Finally, a technical problem exists, inasmuch as studies have shown that the freshwater needs of an estuarine ecosystem are not static annual needs. That is to say, that a range of quantities of inflow is apparently both realistic and desirable for an estuarine environment because extended periods of inflow conditions which consistently fall above or below the maintenance level of the ecosystem can lead to a degraded estuarine environment, loss of important "nursery" areas for estuarine-dependent fish and shellfish species, and a reduction in the potential for assimilation of organic and nutritive wastes. For example, Texas estuaries severely declined in their production of economically important fisheries resources during historic drought events and began to take on characteristics of marine lagoons, including the presence of starfish and sea urchin populations. Likewise, when inflows are extremely high, fisheries production is lowered. The department's studies show that where the estimated seasonal inflow needs of different fishery species are similar, the species reinforce each other's need; however, where species are competitive by exhibiting opposite seasonal inflow needs, a management decision must be made to balance the divergent needs or to give preference to the needs of a particular species. A choice could be made on the basis of which species' production is more ecologically characteristic and/or economically important to the estuary. Whatever the decision, even a well regulated freshwater inflow management regime can only provide an opportunity for an estuary to be viable and productive because there are no guaranties for estuarine productivity.

The results of recent studies being carried out under S.B. 137 will provide the legislature and others in decisionmaking positions some of the important information necessary to establish policies and management programs for each of the State's important estuarine systems. Decisions as to how each of these systems are to be managed, insofar as resolving the issue of the quantity of freshwater inflow to be made available from total freshwater supplies available to meet all freshwater requirements within the State, must be made by the Texas Legislature. Given these decisions, the Texas Department of Water Resources can then develop the necessary mechanisms whereby the Texas Water Commission can administer the appropriation of state-owned water to accommodate the freshwater needs for each of the estuarine systems.

FEDERAL INVOLVEMENT

The Federal Government plays an important, although usually indirect role, in maintaining the proper amount and timing of freshwater inflows to the State's bays and estuaries. Federal policies in the area of water resources are directed to control of flooding, erosion and sedimentation, and construction of multipurpose water projects. The Department of the Army improves stream channels, constructs dams to impound waters for flood control purposes. The Water and Power Resources Service also constructs reservoirs; other Interior agencies, including the Fish and Wildlife Service, impound water in projects for municipal and industrial water supplies, recreation, and fish and wildlife features. The Department of Agriculture constructs runoff and erosion control works and small flood-water retarding projects. The Water Resources Council studies and assesses the Nation's water supplies and grants funds to the States for comprehensive water resource planning.

The Department of the Army is under a blanket directive to examine its flood control projects to consider the probable effect of the project upon any navigable water, which would include bays and estuaries, and to consider other uses that may be properly related to or coordinated with the project. [33 U.S.C. 701 (1917)]. Furthermore, all Federal agencies, in considering flood control projects, are directed to consider nonstructural alternatives to reduce flood damage, e.g., those which avoid water impoundment.

DISCUSSION

Question: Do you feel, in your position where you look at the balance of forces around the undeniably political basis of water decisions, that there is a strong enough constituency for estuarine resources to, in effect, carry the balance, so that the decisions that are made in Texas are going to be properly in balance in reflecting the vital role of water in estuaries and their importance to the public constituency there? Are these strong enough to balance?

Answer: Well, I'm not sure whether it is strong enough to accomplish what one might want to do, but I can testify that there is a strong voice there. Legislation has been passed for example to establish policy to protect the bays and estuaries. Now in terms of securing the adequate financing to get it done on anything other than perhaps a project-by-project basis at the present time, perhaps not.

Question: I think there is feeling among many people that if the public at large were only more cognizant of the resource values of estuaries that we would have a lot less problem in guaranteeing the water supplies we need. I have never been able to quite understand just the nature of the type of promotional or public relations effort that is needed, but you did mention public education and I don't know whether we are talking about trying to jet up a silent spring for estuaries or really get things started or talking about the more tedious and long-term effort of starting it in the school systems. Do you have any thoughts on that at all?

Answer: Sure, I wish that it had been woven into the fourth grade fifty years ago, but it wasn't. When I refer to public education, I would also include public education in about all phases of water. People don't understand hydrology or the hydrological cycle, but they know when they run short of water. You said this is a rainy state, but you have only seen one day's worth. We have been through one of the hottest, longest, driest summers I think I have ever spent in my life. We did have a significant quantity of water in storage and to the best of my knowledge, no industry shut down operations for one day from lack of water. Last year was a relatively wet year and, according to our information, had more fresh water in our eastern basins than was needed for estuarine systems or the lag effect would have shown the fisheries production to be down. In terms of public education, we've got to do both. We've got to have mass information to the water-consuming public, to business and industry to allow them to behave in their own best interests and to be frugal users of water. People talk about conservation, but tell them to treat water as if they had to carry it from the spring house and they wouldn't use so much, I suppose. Widespread mass education as well as fundamental science education in the colleges in the public education system.

Question: My comment, I should probably address to Ken Collins also: One of the problems we are up against--I work in California and I realize there are similar problems in Texas--is that a lot of times by the time information is available, the resource is over allocated and there doesn't seem to be a mechanism to provide for the kind of flexibility that is needed, particularly when we are dealing with a biological system that we don't have adequate information for. If it takes 25 years of studies, by the time those 25 years are gone, we have allocated whatever water we might have needed or that we determine that we need. I'm wondering whether you foresee this? I think Texas may be on the right track, at least coming up with some interim guidelines. I'm sure that you maybe don't look at the studies that you have generated in a four-year period as the final answer and that there is enough flexibility left in the system in case you are wrong and that you can generate some water into the system. I think it is going to involve some ground water management which neither California nor Texas have and that is a toughie.

Answer: You are asking how do we turn the clock back and suggesting ground water management is a way. I'm not sure that is going to help in some cases depending upon what you mean by ground water management. Among the things that we need to do in many of our ground water cases is to get more recharge which means diverting even more of our surface water in a short run into ground water aquifers or shifting the load off declining aquifers in this growing economy onto more surface water, which is placing more competition on the surface water case. In our water rights justfication program, we are adjudicating to the extent that water has not been used and rights are cancelled. That may free up some water. We don't know of cases in which we are presently beyond the point where we have observed that we would need to go back and cancel rights in addition to that.

Question: I know that it is a basic problem in California water rights law also it is sort of a user-lose situation and it encourages agricultural users, in particular, to use their water right because if they don't they lose the right to use the water. There has to be a change in that.

Answer: You are raising a question about an institution with which I happen to agree and, in that respect, that is how to bargain with present water rights holders. In our adjudication program, those rights that cannot be demonstrated to have been used, some are being canceled. Those that have not demonstrated having been used for a period of ten years are being cancelled. Our water commission is also writing permits for major projects with requirements for recent years flow through and releases and return flows, in one particular case, into Corpus Christi Bay; a minimum quantity combination of return flows and/or unused water right. The commission is also writing term permits.

Question: As Jerry has expressed in California we have been fortunate to have at least water protection through legal water protection plans in the bay delta system. I was wondering if Texas is planning to set specific water quality standards with flow standards included for the protection of your estuaries sometime in the future.

Answer: In terms of water quality, the department does establish standards for each of the segments including the bays and estuaries for any discharge. I do not know of any quantity standards that are anticipated at this point. The studies will be the residual at the present time against which all new permit applications will be measured.

FEDERAL AND STATE COASTAL ZONE MANAGEMENT EFFORTS DIRECTED AT ESTUARIES AND FRESHWATER INFLOW

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INTRODUCTION

It was largely due to the efforts of many of you here that Congress was able to bring about the passage of the Federal Coastal Zone Management Act of 1972 (P.L. 92-583). Because research scientists and resource managers were able to start identifying the importance of our estuaries and the problems associated with keeping them productive and because of the initiative shown by some coastal states, Congress declared that:

- the coastal zone is a rich area in a variety of ways and is esstential for the well-being of the Nation,
- that increasing competing demands for land and water uses have led to permanent and adverse changes to fragile coastal ecosystems, and
- that it is in the National interest to effectively manage these resources. (See Section 302 for full text)

It was clear that better decisions had to be made about these important resources. In order to do this, Congress declared some sound policies which to this day have been tried and tested true and provided some important tools to make it all possible. National policies were declared to:

- "preserve, protect, and where possible, to restore or enhance" coastal resources,
- to encourage and assist the state governments to develop, comprehensive coastal management programs which take all interests into accounts,
- to encourage the participation of the public as well as federal, state, and local government decision-makers in the development of these comprehensive programs,
- and with respect to the implementation of those programs, to encourage states and regional agencies to establish "interstate and regional agreements, cooperative procedures, and joint actions regarding environmental programs. (See Section 303 for full text)

Therefore, in order to make these decisions, it was important to provide the states with the tools necessary to develop these comprehensive coastal management programs. Naturally, the largest incentive for participation was the prospect of financial aid and it was not long before all 35 coastal states and territories were participating in the national program.

MANAGEMENT TOOLS

SECTION 305. Under Section 305 the coastal states were given up to five years to develop comprehensive coastal management programs which were to include tackling *all* the problems which focused on the coastal zone. This is one of the great strengths of the program but it also has its drawbacks which I will discuss under PROBLEMS. Suffice it to say that estuarine vitality was just one of the many problems that states had to address. Nevertheless, we saw that most states spent some and even considerable portions of their grants to do the following.

- Inventory their resources which included surveying and mapping bays, estuaries, and wetlands.
- Publish comprehensive bibliographies and other documents useful to managers, researchers and the public.
- Undertake research to delineate just what the problems associated with estuaries were. This was useful for instance, in helping develop the appropriate coastal zone boundaries, policies for management and institutional linkages. This last aspect is important since in many cases we have the differences between upstream and downstream managers. Let me provide you with one such example. Last year in Texas' 305 grant, Task 11 contained four sub-tasks addressing freshwater inflow studies. These funds were used to support the Texas Department of Water Resources to develop a "knowledgeable framework" upon which to base legislation and administrative policies. Provided was $114,000 to collect data, develop various models and facilitate coordination.
- Many undertook educational and public relations programs which were deemed necessary for not only the survival of their developing programs but for what was to take place under their implementation phase as well.

Some of you here have taken part in these various endeavors. Total expenditure under Section 305 came to approximately $70 million. It is, of course, impossible to state just how much of that was spent solely on the subject of freshwater inflows and estuaries because so many of the studies which were undertaken were interrelated with other subjects.

During this time, OCZM did attempt to provide some technical assistance to the states through such sources as the book entitled *Coastal Ecosystems* which was written by our distinguished chairman.

SECTION 306. Section 306, Program Administration, is not an altogether different story but does go a little further. After the states have a federally approved management program, funding becomes a longer term (8 years) proposition which will allow for more in-depth research and studies necessary in making sound management decisions on say, for example, the siting of a facility. Almost all states are now able to provide substantial funding to local governments which are usually the first in the decision-making process, proponents of the activities, and have the least in their pocketbook to look at the implications of their actions. Local governments are developing their own site-specific comprehensive programs which will allow all parties to get a better handle on the problems if they become involved at the appropriate stage of development.

Some of the Gulf States are just now in the process of getting their programs approved. Alabama is approved and we hope Louisiana and Mississippi will be approved shortly (programs were approved in September 1980). Florida and Texas are currently in the Public Hearing Draft stages.

Even though state participation is voluntary, the Coastal Zone Management Act is substantive as well as procedural. States are required to develop enforceable policies to manage coastal resources. I would like to give a few short examples of some of the policies which were developed by the states which address our topic of concern.

California: "30231. The biological productivity and the quality of coastal waters, streams, wetlands, estuaries, and lakes appropriate to maintain optimum populations of marine organisms and for the protection of human health shall be maintained and, where feasible, restored through, among other means, minimizing adverse effects of waste water discharges and entrainment, controlling runoff, preventing depletion of groundwater supplies and substantial interference with surface waterflow, encouraging waste water reclamation, maintaining natural vegetation buffer areas that protect riparian habitats, and minimizing alteration of natural streams." (The California Coastal Act of 1976 - PRC 30000 et. seq.)

Oregon: Goal 16 - Estuarine Resources is a comprehensive goal enforceable by law. It addresses many issues about estuaries and requires comprehensive plans to take these into consideration. It is too lengthy to even summarize here but there is one interesting aspect I wanted to highlight. Namely, many states recognize that coastal zone management affords a good opportunity for restoring degraded estuaries. Under the mitigation requirements of the goal, it is suggested that: "Estuarine areas removed from effective circulation by causeways or other fills, where circulation can be restored or improved through replacement of the causeway with pilings or culverts." (Oregon Statewide Planning Goals and Guidelines 16-19 for Coastal Resources, Effective: 1 January 1977).

New Jersey: New Jersey has developed policies for surface and groundwater uses and for special areas such as shellfish beds relating to freshwater inflows. For example, the Groundwater Use Policy (7:7E-8.6) states: "Coastal development shall demonstrate, to the maximum extent practicable, that the anticipated groundwater withdrawal demand of the development will not cause salinity intrusions into the ground waters of the zone, will not degrade groundwater quality, will not significantly lower the water table or piezometric surface, or significantly decrease the base flow of adjacent water courses. Groundwater withdrawals shall not exceed the aquifer's safe yield." (New Jersey Coastal Management Program, August 1980, page 220).

Louisiana: Guideline 9.1 addresses uses that result in the alteration of waters draining into coastal waters and states that: "Upland and upstream water management programs which affect coastal waters and wetlands shall be designed and constructed to preserve or enhance existing water quality, volume, and rate of flow to the maximum extent practicable." In addition, the program is designating wetland areas suitable for enhancement by freshwater diversion as Areas for Special Management. (Louisiana Coastal Resources Program, 1980, page 62 and 111).

In addition to using the enforceable policies to make management decisions, Section 306 funds can be used to prepare "special area management plans" or address "areas of particular concern." This means that funds could be used to identify specific resource-use conflicts which create the estuarine management problems and propose and implement solutions to those problems.

SECTION 307. Section 307 deals with Federal consistency and even though it has been somewhat controversial in its implementation, it can be useful for state coastal managers in addressing Federal activities such as dam construction which may take place outside of the coastal zone in the upper watersheds and have impacts on the coastal estuaries.

SECTION 308. The Coastal Energy Impact Program has provided both planning and study funds and also construction funds to help ameliorate the impacts on coastal resources created by energy impacts either directly or indirectly. This is a multi-million dollar program of grants and loans and has been used for such purposes as constructing a freshwater diversion siphon in St. Bernard Parish called the Violet Siphon. A recent article in PLANNING describes the background of the necessity for this project and the role of coastal management. It states:

> "When the state initiated efforts to adopt a coastal zone management act of its own to comply with federal funding requirements, Section 305 funds became available and planning for wetlands and coastal areas in St. Bernard went into high gear. There were some reservations about additional layers of federal bureaucracy and regulations being imposed on the area, but after the MRGO (Mississippi River-Gulf Outlet Canal) experience, support from a federal agency to solve some of the problems caused by yet another federal agency was more than welcome...The police jury applied for and received a 100 percent federal grant to construct a freshwater diversion siphon--two 50-inch pipes from the river over the levee and into the Violet Canal. The grant for this project was the first

environmental mitigation construction grant funded under the Coastal Energy Impact Program of the U.S. Office of Coastal Zone Management."

We have many other examples of requests and the use of funds which specially deal with freshwater inflows, saltwater intrusions and the vitality of estuarine resources such as a $60,000 grant to Louisiana to study saltwater intrusion in Tangipahoa Parish and $1,000,000 to Louisiana coastal parishes to construct and rehabilitate oyster reefs on natural seed grounds and to relay oysters from polluted to approved areas in Calcasieu Lake. These are projects which probably would never would have been funded otherwise. The costs in most cases are much to great for local governments to bear and in many cases state governments.

SECTION 309. Section 309 provides for interstate grants and even though it has never been funded, it contains a provision of law which one day may be found useful in dealing with freshwater inflows. This section allows two or more coastal states to negotiate, and to enter into, agreements or compacts which the states deem to be desirable and which are binding and obligatory upon any state or party without further approval by Congress.

SECTION 310. Research and technical assistance is one part of the CZMA which we badly want to see funded. Based upon needs identified by the states and other priority items identified by OCZM, this could be one additional resource in helping get at estuarine problems.

SECTION 315. Estuarine sanctuaries in some cases have been helpful in getting to the problem of freshwater inflow, the most notable is the Apalachicola Estuarine Sanctuary in Florida. During its establishment as a sanctuary, it was recognized that water inflow to the Apalachicola River and Bay was largely dependent upon the Chattahoochee and Flint Rivers in Alabama and Georgia. It was an important tool in focusing the concern of the upstream users with the downstream management goals. Consequently, there were successful negotiations between the three states and they have jointly proposed to the Water Resources Council to undertake a Level B Study which will lead to further understanding of the drainage from these three rivers and the competing demands for this winter.

The purpose of the sanctuaries is to establish outdoor laboratories and to conduct research and educational programs. This is one area where we would like to see more coordinated research taking place in order to make more enlightened management decisions affecting estuaries.

PROBLEMS

While coastal zone management has many significant tools which are being used and will be used in the future to address problems relating to freshwater inflows to estuaries, it obviously can not cure them all.

BOUNDARIES. In order to address inflow problems, one must generally view the entire watershed or wherever major obstructions begin. In some states, this watershed transcends the coastal zone boundary which they have delineated. The states must draw a line somewhere and OCZM has generally supported the state process in defining their boundary. Some states have included all or almost all of their state as the coastal zone because of the watershed principle and others have included coastal mountain watersheds. Still others have narrow boundaries which stop at the 5 o/oo salinity line of the estuary and rivers. Extra efforts are needed to ensure good coordination of governmental actions. In order to shore up this potential weakness, some states have developed Memoranda of Understanding, required consistency of their own state agencies with the coastal policies, and provided funding to other state management agencies to assist in a cooperative mode in addressing the multi-jurisdictional problems.

COMPREHENSIVE PLANNING. Coastal zone management calls for a balance in decisionmaking. This often requires some compromises be made between preservation and development. It is likely that there will be times when the importance of freshwater inflow will get lost in the priorities where there are conflicting national/state and local interests.

COST. While coastal management can currently assist in mitigation and restoration projects, the funding authorization is not projected to be long term. We must learn quickly from past mistakes and avoid the high costs of restoration in the future.

SECTION 306/308 RELATIONSHIP. Section 308 is the best funding source for restoration and mitigation projects, but states which do not participate under 306 are not eligible for 308 funds. There may be states that choose not to participate but may have key estuaries which may cial resources needed to address the issues.

RESEARCH COORDINATION. Much research is being conducted on the health of our estuaries, yet many of the major questions are unanswered and there are still conflicting theories. The academic community, state and the federal governments are expending significant amounts of time and money on this issue. OCZM is contributing as well, but there needs to be some coordination of the resources so that they are utilized to the best advantage. There has to be a better marriage between basic and applied research and between the scientists and the resource managers.

CONCLUSION

The Coastal Zone Management Act was passed because of concerns over estuaries and other coastal resources. Financial assistance and management tools are providing incentives to state and local governments to begin to address problems associated with freshwater inflows or the lack thereof. Special area management planning, enforceable policies, and improved coordination are being brought to bear on the decisionmaking process. Mitigation and restoration projects can help alleviate some of the past problems. While coastal zone management cannot solve all of the inflow problems, especially for some of the larger rivers which transcend the coastal zone boundary, it can be a significant ally with other governmental entities in making better decisions and providing some support with which to do it.

LITERATURE CITED

Meeks, Gordon, Jr. A Louisiana Swamp Story, Planning Vol. 46, Number 2, February 1980.

DISCUSSION

Question: Clark. I feel a little more hopeful now that the coastal management program will involve itself in watersheds, but you've got one little problem up there, it goes something like this: we conservationists over the years have taken on the dredgers, point-source polluters, the wetland fillers, and real estate interests. We have even taken on the nuclear plants. Now it is 1980 here on the coast and I ask who is next? Who are we missing? Who are we not taking on? Well of course, I think we all know that it is time to take on the farmers. The CZM won't take on the farmers. The Corps of Engineers refuses to take on the farmers. The EPA tried it, got whipped and quit. That is my question, who will take on the farmers?

Answer: Miermet: It is a very difficult thing. California, in planning for their coastal zone, has a much larger boundary when they tried to address the issue of the very productive agricultural lands there and they tried to get some handle on the management aspect but that was rejected and the boundary was quite a bit narrower than the coastal commission had proposed. It took out the forests and the agricultural lands. I think in a state like Louisiana when you fly over it, you see the wetlands and the agricultural lands side by side. Most states do have some policies that address agriculture and the purposes. I think that most states find that as being the highest use of the coastal zone, however, it is not so much a regulation as it is some other aspect of trying to protect agriculture.

Question: My name is Chris Temke. I'm with the Florida Department of Natural Resources: I just wanted to elaborate for a moment on a point that Ben made earlier this afternoon that there was a definite lack of data which are needed to understand what the problems are in the estuaries, and what steps should be taken to resolve the problems and to mitigate these problems. I think the national estuarine sanctuary problem fits quite well in trying to answer this question. One of the major purposes of the program is to set aside areas for long term research and education, to establish a data base, and to understand what a relatively or completely undisturbed system is like, and I feel as though these areas are new. They have only been in existence a few years and should be looked at quite closely by people that are thinking about doing research. Certainly, in the area of Rookery Bay, I'm trying actively to bring university people down here to do research, so we can develop a data base in this area which can be used to help develop a coastal zone policy.

Comment: Clark. Beyond this research and education, I have noticed lately that some of the estuarine sanctuaries have an agenda of conservation or resource management as well. Certainly Apalachicola, Rookery Bay, and Alcorn Slough have really increased the state-of-the-art as far as estuarine management is concerned. I think that there is more progress made in ultimate long-term benefits and coastal zone management in the estuarine sanctuary program than any other part of the CZM program. I really am very enthusiastic about that. I hope we can invent something that will widen that out so that we don't have to restrict this type of designation of Federal assistance to local areas and unit resources. They will not have to restrict research and education to representative areas here and there, since every estuarine community that wants it, ought to be able to have the benefit of technical assistance and the designation and what comes with it in the way of Federal, state, and local cooperation and partnership. I think it is really a dynamite program.

CORPS OF ENGINEERS POLICIES ON FRESHWATER INFLOW

Walter B. Gallaher

U.S. Army Corps of Engineers, Dallas, Texas

INTRODUCTION

It is indeed a privilege to participate in today's panel session. I am substituting for Brigadier General Hugh Robinson, our Division Engineer, Southwestern Division. General Robinson asked that I express his sincere thanks to the USFWS for its ivitation and sends his sincere regrets for being unable to participate in today's session. General Robinson did express his keen interest in this most important symposium and believes that the results and conclusions reached at this 3-day symposium will be most important in guiding our future efforts in conserving the valuable fishery and shellfish resources of our Nation's estuaries.

CORPS - CAPABILITIES AND CONSTRAINTS

The Corps of Engineers had planned, constructed, and is presently operating more than 400 reservoirs across the United States. However, the water is owned, and water rights are controlled by individual states, usually a state water resources board within the state where the project is operated. Therefore, with the water use controlled by others, release of waters downstream or use for purposes other than authorized purposes are not usually possible without the state's agreement. During the planning process, various water-use needs, including mitigation requirements, are considered and those feasible uses provided for in the project plans. Even reservoir releases for mitigation need state concurrence to ensure the water is not diverted before it serves the mitigation purpose.

The degree of control over water uses and the availability of so called "surplus water" vary with the states. Generally in the western states, particularly in the semiarid areas, water uses and availability are much more closely regulated than in the eastern states where more water is usually available. In states such as New Mexico and Texas, where all the available water has been appropriated, the states exercise full control over water use. In some areas, the Corps has some degree of flexibility in operation of projects and releases of flood waters. In such cases, it is possible to work our water-level management plans for reservoirs and downstream releases for the benefit of fish and wildlife, and we have implemented these plans at many projects.

Several existing authorities provide the Corps with direction to study and develop solutions to instream flow problems:

a. Specific project or basin studies to solve a particular problem.

b. Sec 216, PL 91-611, Completed Project Review. This section authorizes review and report to congress of the operation and maintenance of completed projects when found advisable due to significant changes in physical or economic conditions.

c. Sec 102(b), PL 92-500. This section makes it clear that the Corps will determine the need and value of storage for all streamflow purposes other than water quality control. This sounds all well and good; however, the problem of planning storage for fisheries needs is compounded when projections of the components of future flows and their relation-ship to state water laws are considered.

d. Sec 22, PL 93-251, Comprehensive Planning Cooperation with the states. Mechanisms exist to do limited project work as re-quested by specific states.

e. Sec 65, PL 93-251, Water Quality Storage. This section permits conversion of water quality storage in authorized reservoirs if it is "not needed, or is needed in a different amount" to other authorized purposes of the project when Environmental Protection Agency (EPA) determines that such storage is unnecessary.

f. The continuing responsibility for project operation and maintenance requires frequent reanalysis of our water control management to ensure instream flow procedures are the best use of the resource to accomplish the authorized purposes.

President Carter, in his Memorandum on Environmental Quality and Water Resources Management, 12 July 1978, directed all Federal agencies to cooperate with states to improve the operation and maintenance of existing water resource projects to address instream flow needs. The President's Memorandum stated in part: "In cooperation with the states, federal agencies shall improve, where possible, the operation and management of existing water resources projects to protect instream uses. While not interfering with state laws and responsibility, federal agencies shall set a strong example in recognizing and protecting legitimate instream flow needs."

"In the planning stage, federal agencies shall establish and provide for the streamflow necessary to maintain instream needs below dams or other facilities. For existing water resources project legislation that now lacks provisions for maintaining instream flow, and where commitments and economic feasibility permit, federal agencies working in cooperation with the states shall develop legislative amendments to correct this situation."

Instream flow needs have perplexed water resources planners for some time. There have been several reasons why the instream issue has been unclear. First, it is not uncommon for planners and developers to see instream uses and out-of-stream uses as being in conflict. Historically, the legal and institutional systems favored out-of-stream uses. Second, many agencies have a narrow perspective of the problem because their agency mission is oriented to one use or another. As a result, even agencies exercising control over related instream flow uses have tended to differ in the development of criteria and methods. Third, the use of the term "minimum flow" has created problems. Traditionally, minimum flow has been used to describe the ultimate minimum that developers must leave in the stream, having taken all the rest. Overuse of this term has tended to crowd the real issue--that there are instream uses, each having a specific range of flow requirements. For the purpose of this presentation, I am using this definition of instream flow uses: "All beneficial uses of water in a stream channel, such as fish and wildlife habitat, navigation, hydropower, recreation, and aesthetics." There are four general categories in which instream flow problems can be classified: (1) quantity, (2) quality, (3) physical barriers, and (4) flow fluctuations. Instream flow problems can also be a combination of these four categories. Furthermore, problems may result from the cumulative effect of several small projects, any one of which by itself would not cause instream flow problems.

Implementation of the President's directive has brought about increased emphasis by the Corps on water control management in our projects. As a first step in establishing a Corps-wide approach to meeting the President's directive, the Corps is currently making a project-by-project evaluation of all its existing water resources projects. These evaluations will be used to assess the magnitude of instream flow-related problems and needs, the potential costs required to meet these needs, the opportunities that might exist for enhancing instream flows affected by projects, and will serve as a basis to establish priorities in carrying out the necessary action. Until the information is gathered and evaluated, high priority projects for which solutions have been proposed, where commitments and economic feasibility permit, will be submitted by Corps districts as operation and maintenance items for inclusion in the President's budget.

As we continue our evaluation of instream flow problems and needs, consideration will be given to developing a separate program and funding source to solve instream flow needs, such as a line item in the President's budget.

In addition to the above, all existing projects here in the Southwestern Division are being evaluated with respect to stream flows for fish and wildlife needs. This evaluation is not of the detail frequently associated with the planning of new projects. The time and funding constraints require that this information be based upon data on-hand. This information will, of course, be incorporated into the overall evaluation of instream flow needs.

It is the policy of the Chief of Engineers that reservoir regulation procedures be evaluated continually. The objective of this policy is to improve water management in light of changing conditions.

There are a number of available methodologies for determining the water requirements for instream uses, but none of these methods is universally applicable. Policy studies related to instream flow requirements are being conducted under the auspices of the Institute for Water Resources. Technical studies are presently ongoing under the Corps Environmental and Water Quality Operational Studies Program at the Waterways Experiment Station. These studies will assist the Corps in future planning needs in project formulation studies. Areas of analysis include: (1) evaluating technical methods presently being advanced through other federally sponsored programs, such as the Cooperative Instream Flow Group in Fort Collins, Colorado, (2) appraising the impact of existing compacts operating at state and river basin level; and (3) reviewing and appraising emerging instream flow policies being developed. With regard to our Regulatory Functions Program, we will review all existing and potential permit applications to determine: (1) if at the time of permit approval, instream flows were cited as a need beyond that identified by the applicant, and (2) if any pending applications during a public interest review have recognized the need for instream flows. Conflicts will need to be cited and solutions proposed.

SUMMARY

Instream flow needs is a concept whose time has arrived. Unfortunately, the problem has not been defined explicitly to allow the development of a corrective uniform methodology. An intensive evaluation effort is being made to define the magnitude and extent of the problem so that an action program can be formulated.

It is conceivable that in the not-so-distant future with expected human population growth in the United States and consequent increased demands on consumptive use of stored water, new reservoirs will be planned to satisfy all identified needs. These may include storage and releases earmarked for replenishing freshwater inflows to bay and estuarine areas. However, there are many problems that will have to be overcome before this can be done. First, higher priority must be placed on water use for such purposes as fish and wildlife, and second, someone will have to pay for the storage and O&M costs. Further, once you have ironed out these problems, there are other constraints to getting this water downstream to reach the bays and estuaries, such as channel losses, encroachment on water use, etc. The Corps is dedicated to work with all concerned parties to best meet all the water needs of our Nation--including freshwater flows to estuaries.

DISCUSSION

Comment: You mentioned the concept of dilution as the solution to pollution. In California we have been told that is one reason we can't have instream flows because dilution is not a solution to pollution. I advise people to counter that by saying that low flows make no shows out of Cohos.

Comment: I'm Jerry Valence from the California Resources Control Board. One of the concerns that we have had in California relates to economics. I get the feeling that a lot of people are going to try to quantify economically the benefits of estuaries, and I suggest that there is a potential danger in that you are not going to be able to quantify adequately what we consider to be intangible benefits of estuaries. I think that maybe something we may want to consider in our deliberations over the next few days is that there are intangible benefits, such as the benefit of being able to take your grandson fishing fifty years from now. What kind of benefit is that for estuaries? I'm not sure we will ever be in the position of quantifying all those impacts economically. I think what we need to do is set forth what we feel are appropriate goals to meet and then try to meet them. Economics is a part of that, but I don't think you can do a dollar for dollar comparison and expect estuaries to come out on the top every time. There are other benefits which we just can't quantify that we need to recognize in our deliberations.

Reply: I would accept that there are hopes and expectations of our society that are beyond what we can measure in dollars and that is a tough one. Anybody else care to comment on that subject of economics? I know it is a burning issue that we are never going to solve. I think we are burned out.

BANQUET ADDRESS

Honorable Robert L. Herbst

Assistant Secretary of the Department of the Interior,
Fish, Wildlife and Parks

I always enjoy coming to Texas and often recall the first time I made a speech here. I was commissioner of Natural Resources in Minnesota, and, before the meeting, was complaining about my problems to a group I had just met. I said, "I've got 4,000 employees, a yearly payroll of 189 million dollars, and I oversee 57 million acres of land. What a headache."

One of the listeners, a wind-burned Texan, said, "Son, I can understand your complaints, your outfit is almost as big as my ranch."

It was that same night after my speech that I knew I had said something to offend. As I sat down at my seat on the dais, a brawny cowboy pulled a chair up next to me and placed his six-shooter on the table. I must have turned a little pale, because he said, "Don't worry ain't nuthin' gonna happen to you. We'd just like to get the guy who invited you here."

Well, I hope that won't be the case tonight, but I am prepared to take my chances because your symposium subject is tremendously important and because what government does and has done has great impact on the water, coastline, and estuaries of America.

For those of us concerned with the preservation and conservation of our national, natural resources, the decade of the seventies was an extraordinary one--one marked by great public education, interest, and support. And because that public support was reflected in a series of legislative landmarks and by many positive executive and administrative acts at state and Federal levels, we look back with great pleasure and satisfaction on an Environmental Decade.

Yet, for all of that, while estuarine concerns were not totally ignored, they were not nearly as central a concern as we might have hoped. You, however, persisted in your research and your application of existing knowledge and I salute you for that.

You have known what many others seem to have ignored: that many of our estuaries are producing less and show less diversity than in the past--seriously ill, if not slowly dying.

You know that estuaries help feed a hungry world and that their destruction leads to certain and inevitable misery. You know that we cannot take the most productive ecosystems in the world--the natural factories where fresh water and salt water mix--the production sites, if you will, of immense populations of commercially valuable shellfish, crabs, and finfish, treat them indifferently and casually and expect to survive well. You know that we cannot drain, fill, pollute, or destroy estuaries in the name of progress or as a simple sin of greed without ultimately inviting widespread distress.

The coast--barrier islands and estuaries--may indeed be America's last frontier. How we behave here may determine to a great degree what the quality of life will be for future generations.

Hopefully this symposium will itself be a watershed in turning both professional and public attention toward estuaries and in turning destructive forces away from them.

You deserve and you will have important allies in this and we will need them in the decade ahead of us--one which may be more difficult for environmentalists than the one just past.

Our history,in many fields both social and scientific, has been one of great activity followed by quiescense, of movement upward, followed by rest on a plateau. Add in uncertain economic conditions and a strong budget-cutting impulse on every level of government and the eighties seem filled with difficulties.

Despite all of that--despite obstacles, pitfalls, and those to whom our cries mean nothing--there is hope. There is hope that the people's attention will not stray from our concerns and the Nation's--nor the world's--environmental needs.

President Carter has declared this year, "The Year of the Coast," and we in government have tried to follow his direction and to reach for his goals. Tonight, I want to restate his goals, speak of what we are doing, knowing what he has set forth is non-partisan and nonpolitical.

He said in his 1979 message on the environment, and I quote, "America's coastlines are extraordinarily varied, productive and beautiful. The coastal zone is subject to unusual pressures, both from natural causes and human activities. The opportunity of our citizens to enjoy beaches, bays, and marshes is often threatened..."

He then set as his goals:

---To protect significant national resources such as wetlands, estuaries, beaches, dunes, barrier islands, and fish and wildlife.

---Manage coastal development to minimize loss of life and property from floods, erosion, saltwater intrusion, and subsidence.

---To assist in siting of energy, defense, transportation, and recreational facilities.

---To increase public access.

---To preserve and restore historic, cultural, and aesthetic coastal resources.

---And to coordinate and simplify government decision-making.

Some progress has been made in meeting these goals--some substantial progress, I think--but it hasn't been easy and it hasn't been total. What happens in my home state of Minnesota where the Mississippi begins may seriously affect Louisiana where it ends. Surely what happens in St. Louis and Memphis and the lands around the lower river does. It is obvious yet it seems a lesson which has to be relearned by some almost daily.

Management and protection of the coastal zone will never be simple because many people and many diverse interests and areas are involved. We must tie together inland river and watershed planning and management to coastal planning and management.

They cannot be isolated, one from the other, pretending in an Alice in Wonderland World that fresh water, sediments, and nutrients will miraculously appear in estuaries without being carried there by our streams and rivers.

The people I work with at the Department of the Interior--in the Park Service, in Fish and Wildlife particularly, and in the Heritage Conservation and Recreation Service--understand all of this interdependence well. They understand and take seriously their special responsibility for our coasts.

We oversee 115 national wildlife refuges in the coastal zone and they cover 7.2 million acres--more than that Texas ranch. We have 40 national park service areas along our coast, including some of our most sensitive barrier islands.

HCRS, the Heritage Conservation and Recreation Service, newer and less well known than Parks or Fish and Wildlife--has an awesome responsibility in working to preserve the barrier islands which, of course, surround many of our estuaries.

These islands functioning in a life-giving rhythm with estuaries and saltwater marshes and dunes have qualities unequalled and virtually unparalleled.

They are unique in their animal and plant life, providing a favorable habitat not only for fish and shellfish, but for reptiles, birds, and mammals.

Barrier islands provide protection for our mainland and recreational activities of a special sort for millions of people whose souls are refreshed and whose spirits soar like the osprey who nest and feed nearby.

This is but one example of increased Federal awareness and involvement in the environmental health of our coasts. There are others.

The responsibility to identify "approximate freshwater needs" of estuaries was given to the Water Resources Council in 1975 and it has an "independent review" function of all federally-funded water projects. That is significant.

Our Fish and Wildlife Service, through its responsibilities in implementing the coordination act, has considered the freshwater needs of estuaries in its assessments. We know that there are no reserved Federal water rights for estuaries, but we intend to protest, or curtail where we can, any action by another Federal agency or by a state agency or by individuals or corporations which will result in a changed ecology in our national wildlife refuges or our national parks along the coasts.

Let me list several other projects which some of you are involved in, but which all of you should be aware of.

The FWS has ongoing studies in the Nueces-Corpus Christi and the Matagorda Bay estuaries of the

Texas coast to determine the effect of reducing freshwater inflow.

The FWS is working closely with the U.S. Army Corps of Engineers in New Orleans to develop plans and methods for reintroducing fresh water into marshes and estuaries along the Louisiana coast that have suffered saltwater intrusion.

On the West Coast, the FWS is working with the State of California and the Water and Power Resources Service to develop water plans that will protect fish and wildlife habitats in the Sacramento-San Joaquin estuary.

The Pacific Northwest Basin Commission is developing a data base for planning the management of the Columbia River estuary.

The FWS National Coastal Ecosystems Team has completed ecological characterizations--mostly from available information--on six segments totaling 2,100 miles of U.S. coastline.

The FWS is making a strong effort to protect the remaining bottomland hardwoods along a number of rivers, including the Mississippi.

It's interesting, by the way, to note that 56 percent of bottomland hardwood habitat in the lower Mississippi River alluvial plain was cleared between 1937 and 1978--primarily for agriculture. Its effects were horrendous and I'd wager that national gains were far less than national losses.

To prevent further losses--some irrevocable and beyond repair--we are going to have to have a more sensible approach to water resource planning. In order to protect our river and estuary ecosystems which are so vitally connected physically and ecologically, we need a system of coordination and cooperation between engineers, planners, ecologists, natural resource managers, economists, and citizens.

Rachel Carson, in many ways the patron saint of our environmental interests, once quoted Albert Schweitzer who said, "Man has lost the capacity to foresee and forestall. He will end by destroying the earth."

You at this symposium are among a small party devoted to foreseeing and forestalling frightful events. With the help of your wisdom, maybe we will not end by destroying the earth. At the very least, we will start by protecting the estuaries which give life.

CHAPTER 1

FRESHWATER INFLOW STUDIES ALONG THE MID- AND NORTH ATLANTIC COAST

CHESAPEAKE BAY LOW FRESHWATER INFLOW STUDY

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U.S. Army Corps of Engineers, Baltimore, Maryland

ABSTRACT

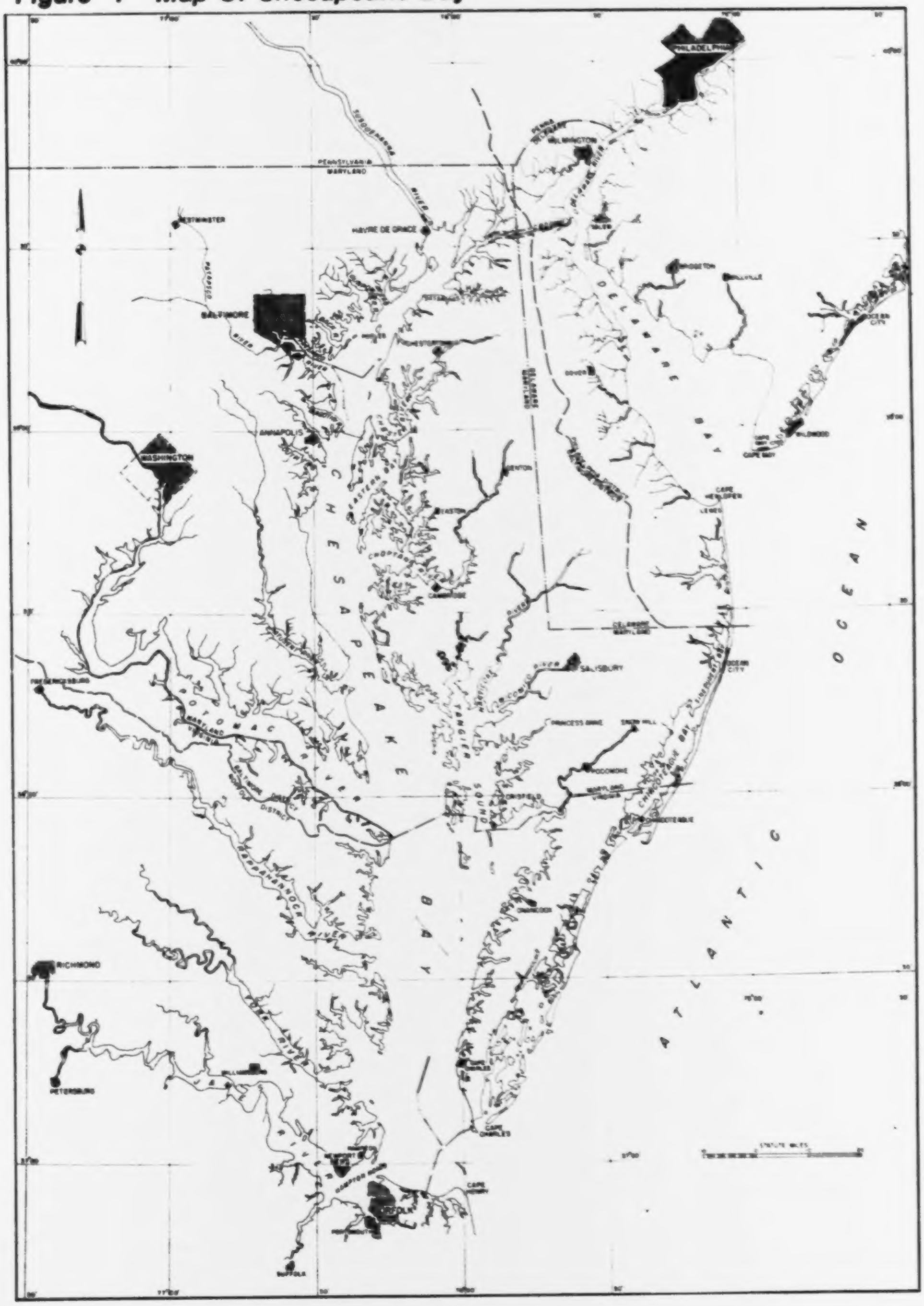
Chesapeake Bay is the largest estuary on the Atlantic coast of the United States and one of the more important estuaries in the world. It is nearly 200 miles long and varies in width from 3 miles to 30 miles. Like all estuaries, it depends upon the inflows of freshwater to maintain its salinity regime. Salinity variations, spatial and temporal, constitute the most significant physical parameter influencing the circulation dynamics of the estuary and the types of aquatic species which reside in it. The quantity of fresh water flowing into the Chesapeake may be substantially reduced in the future due to a marked increase in the consumptive use of water. The Corps of Engineers Low Freshwater Inflow Study was conceived as a result of the concern over this increased consumptive use. The objectives of this study are to assess the environmental, economic, and social consequences of these reduced flows and if appropriate, to formulate criteria for minimum freshwater inflows. A major portion of this work will be based on the results of a series of tests conducted on the Chesapeake Bay Model.

INTRODUCTION

The Chesapeake Bay is the largest estuary on the Atlantic coast of the United States and one of the more important estuaries of the world. The bay is about 200 miles long and varies in width from about 3 miles near Annapolis to about 30 miles at its widest point near the mouth of the Potomac River. It has a free connection with the waters of the Atlantic Ocean at its southern extreme and is connected near its northern extremity to the Delaware Bay through the Chesapeake and Delaware Canal. The tidal shoreline of the bay and its tributaries is about 7,000 miles long while the water surface area is about 4,300 square miles. The surface area of the bay proper is about 2,200 square miles and its mean depth is less than 28 feet. The entire system, including the tributaries to the head of tide, averages about 21 feet deep. There are, however, deep holes which occur as long narrow troughs. These troughs are thought to be the remnants of the ancient Susquehanna River Valley which have not been filled by post-Pleistocene sediments. The deepest of these holes (175 feet) is located near Kent Island where the Chesapeake is at its narrowest. Figure 1 is a map of the Chesapeake Bay Area.

The Chesapeake Bay receives water from a basin over 64,000 square miles in area. There are more than 50 tributary rivers with widely varying geochemical and hydrologic characteristics contributing fresh water to it. The largest river on the East Coast of the United States, the Susquehanna, drains 42 percent of the basin. The Potomac River drains 22 percent, while the Rappahannock-York-James system drains about 24 percent.

Figure 1 Map Of Chesapeake Bay


PHILADELPHIA
WILMINGTON
PENNSYLVANIA
MARYLAND
WESTMINSTER
HAVRE DE GRACE
BALTIMORE
DELAWARE BAY
ANNAPOLIS
WASHINGTON
EASTON
CAMBRIDGE
CAPE MAY
CAPE HENLOPEN
SALISBURY
OCEAN CITY
FREDERICKSBURG
POTOMAC RIVER
CHESAPEAKE BAY
PRINCESS ANNE
SNOW HILL
POCOMOKE
ATLANTIC OCEAN
RICHMOND
PETERSBURG
CAPE CHARLES
CAPE HENRY
SUFFOLK
STATUTE MILES

The mean tidal fluctuation in Chesapeake Bay is small, generally between 1 and 2 feet. Saline water intrusion is highest along the east side of the estuary due to the influence of the coriolis effect and the fact that the larger rivers are on the western shore. Salinities range from about 33 ppt inside of the mouth of the bay to near zero at the north end of it and at the heads of the embayment's tributary to it. Salinity variations, spatial and temporal, constitute the most significant physical parameter influencing the circulation dynamics of the estuary and the types of aquatic species which reside in it.

The ebb and flow of tides are the most readily perceptible water movements in the Chesapeake. Average maximum tidal currents range from less than 0.5 knots to over 2 knots. The tidal currents along with wind supply the necessary energy for the mixing of salt water from the ocean and fresh water from the tributaries. Tides, being oscillatory by nature, do not function as a mechanism for the net transport of water, suspended solids, or dissolved material. Within the bay proper and its major tributaries there is superimposed on the tidal currents a non-tidal, two-layered circulation pattern that provides a net seaward flow in the upper layers and a flow up the estuary in the deeper layers.

The physical and chemical dynamics of the estuary make it a biologically special place. Salinity variations within Chesapeake Bay have allowed colonization by aquatic organisms of both fresh and salt water origin. Freshwater biota remain in the fresher to slightly brackish portions. Many marine animals return to fresh water to reproduce. Also, with the aid of estuarine currents, the eggs and larval forms of some species are transported to less saline waters to hatch and develop.

PROBLEM IDENTIFICATION

Like all estuaries, Chesapeake Bay is dependent on the inflow of freshwater to maintain its salinity regime. The species that live in the bay year round and others that utilize it only in various portions of their life cycle are generally able to survive the natural daily, seasonal, and yearly variations in salinity. Drastically reduced freshwater inflows during droughts or reductions of less magnitude over a longer period of time can impose environmental stress. This may threaten the health or even the survival of species sensitive to particular ranges of salinity, or may limit the spawning opportunities of other estuarine species. Changes in freshwater inflow can also alter existing estuarine-flushing characteristics and circulation patterns. In short, the character of Chesapeake Bay and the health and well being of the ecosystem depend on established physical, chemical, and biological patterns in the bay. These are, in turn, intimately related to the volumes of freshwater inflows and the seasonal variations in these flows.

In recent Corps of Engineers' studies it was found that, if present trends continue, the future quantity of fresh water flowing into Chesapeake Bay could be substantially less than it is today. This predicted reduction is primarily a function of increased consumptive use of water from the bay's tributaries resulting from an increasing population, the need for more food, an increasing level of economic activity, advances in technological processes, and increasing use of evaporative cooling processes.

The population of the Chesapeake Bay Region is expected to nearly double in the next 50 years. The majority of these people will probably be served by central water supply systems and it has been demonstrated that a typical community will return to a stream only 75 to 90 percent of the water withdrawn from it. It is possible that none of the water would be returned if an inter-basin transfer is involved.

An increasing population needs more food. Because of limited land resources and economic factors it will probably be necessary to substantially increase irrigation practices. Almost all of the water used for this purpose never returns to the system or takes so long to return that, for all practical purposes, it is considered lost.

As economic activity expands, more water will be needed for industrial processes. This alone would result in a substantial increase in consumptive use. There is, however, a definite trend toward an increased use of processes such as cooling towers, which involve the evaporation of water. The consumptive use of water associated with this is often markedly greater than some other types of processes.

Nearly every tributary to Chesapeake Bay will be subjected to the consequences of increased consumptive uses of water. Table 1 has been prepared in order to assist in placing the magnitude of these uses in perspective. Shown on this table are the actual discharges of the Susquehanna River during August, September, and October of the drought year 1964, the anticipated consumptive uses of water in the year 2020, and the consequential reduced freshwater inflows. These reduced inflows have been adjusted to reflect the influences of several dams which have been constructed since 1964 and, where appropriate, the discharges from wastewater treatment plants.

Under low flow conditions these consumptive uses often constitute a considerable portion of the natural flow in a river. For instance, the losses in the Susquehanna River during this dry period constitute from 24 percent to 66 percent of the natural river flow. Similarly, in the Potomac River, consumptive losses are from 40 percent to 70 percent and in the James River 11 percent to 36 percent of the natural river low flow.

During periods of higher flows, the consumptive uses are only a small fraction of the total river flow. On the average, consumptive uses constitute 4 percent of the 39,000 cfs average flow in the Susquehanna River, 6 percent of the 7,900 cfs average flow in the James River, 7 percent of the 11,000 cfs average flow in the Potomac River and 5 percent of the 76,600 cfs average contribution of fresh water by all tributaries to the bay.

There is widespread concern relative to the potential consequences of these reduced freshwater inflows. The Susquehanna River Basin Report Coordinating Committee in its 1969 report identified this as a high priority study item and both the Susquehanna River Basin Commission and the State of Maryland have written to the Baltimore District Engineer requesting that the Corps of Engineers perform studies addressing the problem. In addition, the Chesapeake Bay Study Advisory Group,

Table 1. Chesapeake Bay low freshwater inflow study. Susquehanna River weekly average low freshwater inflows with and without consumptive losses (cubic feet per second).

Week Ending	Recorded Flow	Consumptive Loss (2020)	Reduced Flow	Percent Reduction
5 Aug 64	5087	1752	3335	34
12 Aug 64	7155	1752	5403	24
19 Aug 64	4900	1752	3148	36
26 Aug 64	3968	1752	2216	44
2 Sep 64	3955	1632	2323	41
9 Sep 64	3182	1632	1550	51
16 Sep 64	2613	1632	981	62
23 Sep 64	2415	1632	783	68
30 Sep 64	2466	1632	834	66
7 Oct 64	3980	1600	2380	40
14 Oct 64	3182	1600	1582	50
21 Oct 64	3462	1600	1862	46
28 Oct 64	3223	1600	1623	50

Steering Committee, and Citizens Advisory Committee have identified reduced inflows as one of the more important problems facing Chesapeake Bay. Thus, the Chesapeake Bay Low Freshwater Inflow Study was conceived in an atmosphere of almost universal concern over the potential economic, social and environmental impacts of reduced freshwater inflows.

STUDY OBJECTIVES

Three objectives have been established for the Corps of Engineers' Low Freshwater Inflow Study as follows:

1. To provide a better understanding of the relationship between the salinities in the Chesapeake Bay and the freshwater inflows contributed by its tributaries;

2. To define the environmental, social and economic impacts of both short- and long-term reductions in freshwater inflow; and

3. To recommend the minimum flow or schedule of flows that should be maintained in the major bay tributaries in order to assure the integrity of Chesapeake Bay.

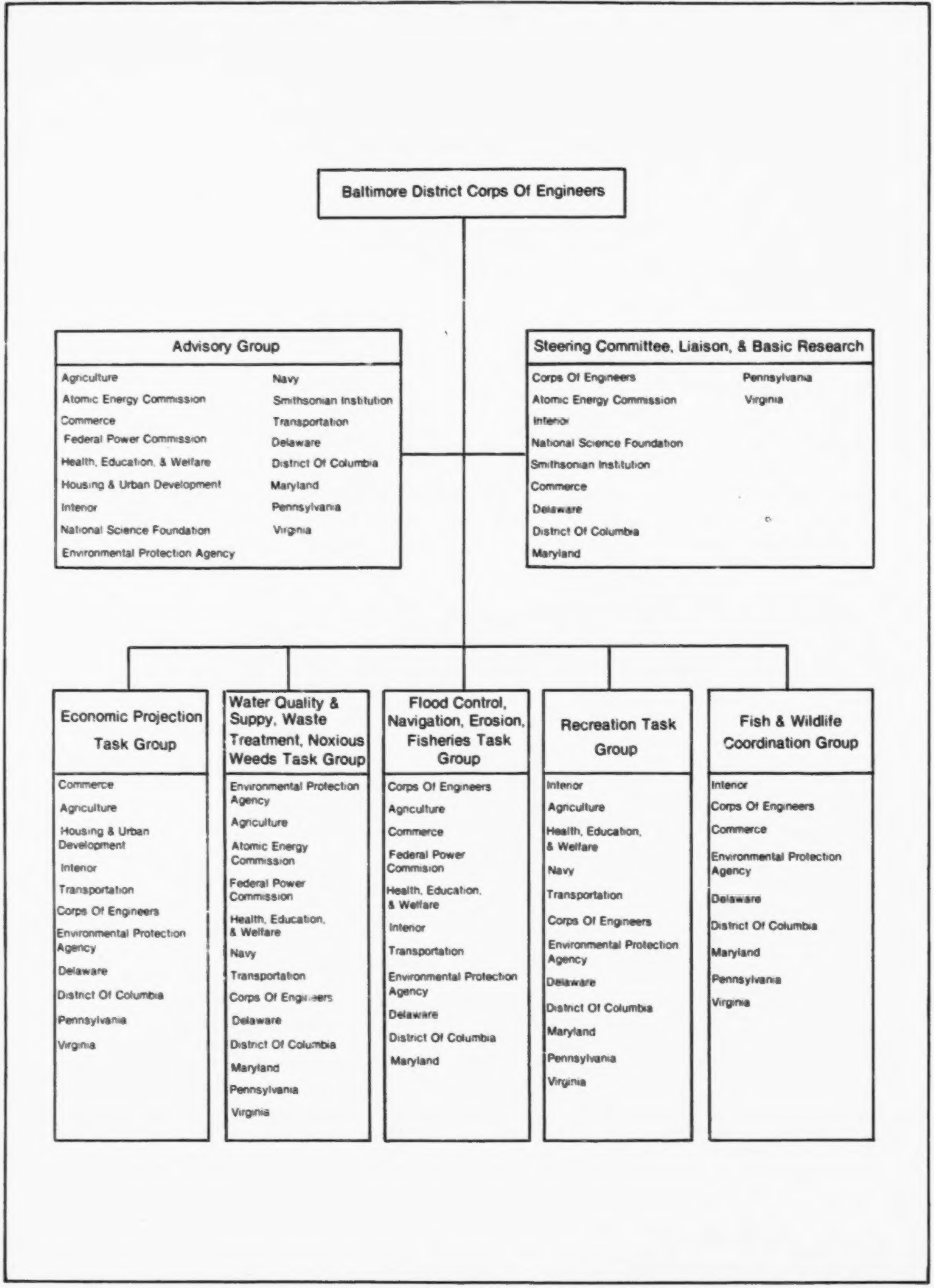
STUDY ORGANIZATION

The Low Freshwater Inflow Study as well as the other elements of the Corps' Chesapeake Bay Study Program are of such a complexity and magnitude, and involve so many varied disciplines that no single entity could be expected to have the requisite personnel, equipment and technical know-how necessary to accomplish the many special studies that are required. Such expertise does exist among the many agencies which have historically been responsible for certain features of water resource development. We have, therefore, established the study organization shown in Figure 2. This organization was conceived under the basic premise that the study would be a coordinated partnership among Federal and state agencies, interested educational institutions, and the public. Each agency is charged with exercising leadership in those disciplines in which it has special competence. For instance, the Annapolis field office of the Fish and Wildlife Service has the lead role in those aspects of the Low Freshwater Inflow Study that are related to environmental concerns.

To facilitate the realization of these ends, an Advisory Group was established. The major purpose of this Advisory Group is to assist the district engineer in establishing broad guidance and providing general direction under which all participants will work. The group takes into consideration the views and needs of those involved in the study and advises the district engineer on establishing policy regarding both the execution of tasks and the resolution of conflicts that may arise.

The Steering Committee consists of scientists who are knowledgeable about Chesapeake Bay. This committee is responsible for reviewing the work of other groups and bringing to their attention any pertinent advances in the art of water resource development or the environmental sciences. This committee also formulates plans for scientific activities that are a necessary adjunct to this study. For example, the Steering Committee has provided the primary guidance for conducting the Low Freshwater Inflow Study, particularly those aspects related to biological evaluations and tests on the Hydraulic Model of Chesapeake Bay.

Figure 2 Organization — Chesapeake Bay Study


Baltimore District Corps Of Engineers
Advisory Group
Agriculture
Atomic Energy Commission
Commerce
Federal Power Commission
Health, Education, & Welfare
Housing & Urban Development
Interior
National Science Foundation
Environmental Protection Agency
Navy
Smithsonian Institution
Transportation
Delaware
District Of Columbia
Maryland
Pennsylvania
Virginia
Steering Committee, Liaison, & Basic Research
Corps Of Engineers
Atomic Energy Commission
Interior
National Science Foundation
Smithsonian Institution
Commerce
Delaware
District Of Columbia
Maryland
Pennsylvania
Virginia
Economic Projection Task Group
Commerce
Agriculture
Housing & Urban Development
Interior
Transportation
Corps Of Engineers
Environmental Protection Agency
Delaware
District Of Columbia
Pennsylvania
Virginia
Water Quality & Suppy, Waste Treatment, Noxious Weeds Task Group
Environmental Protection Agency
Agriculture
Atomic Energy Commission
Federal Power Commission
Health, Education, & Welfare
Navy
Transportation
Corps Of Engineers
Delaware
District Of Columbia
Maryland
Pennsylvania
Virginia
Flood Control, Navigation, Erosion, Fisheries Task Group
Corps Of Engineers
Agriculture
Commerce
Federal Power Commision
Health, Education, & Welfare
Interior
Transportation
Environmental Protection Agency
Delaware
District Of Columbia
Maryland
Recreation Task Group
Interior
Agriculture
Health, Education, & Welfare
Navy
Transportation
Corps Of Engineers
Environmental Protection Agency
Delaware
District Of Columbia
Maryland
Pennsylvania
Virginia
Fish & Wildlife Coordination Group
Interior
Corps Of Engineers
Commerce
Environmental Protection Agency
Delaware
District Of Columbia
Maryland
Pennsylvania
Virginia

The task groups are functioning as basic work groups in each of the five study areas. The individual task groups are composed of those agencies interested in the study problems assigned to it. Through this mechanism it is intended that constant liaison, work review, and requisite agency interaction is maintained.

A public participation program has also been established so that the views of the general public are incorporated in the study process. A major component of this program is a Citizens Advisory Committee composed of members of the Citizens Program for Chesapeake Bay--an umbrella organization consisting of environmental, industrial, and political groups.

STUDY METHODOLOGY

In the Low Freshwater Inflow Study, primary efforts have been purposely focused on those parameters directly related to salinity because it was apparent early in the work that there is not a sufficient data base available to address many of the other factors which may be affected by changes in freshwater inflows. One of these is the problem of defining the mechanisms of biotic transport--a phenomenon whereby many of the non-swimming species are transported to their place in the estuary by currents. There is, however, only a minimal knowledge of the current patterns of Chesapeake Bay. Even more serious, there is little understanding of how species movement relates to these current patterns.

Other areas where the data base is apparently inadequate include the interaction of individual species and families of species, and the relationship of freshwater inflows to sediment patterns, the nutrient budget, and temperature. Further research is needed in all these areas before there will be a sufficient data base available to fully address them in management oriented studies such as the Corps of Engineers' Low Freshwater Inflow Study. This is not to imply that these factors are being ignored, rather, they are being addressed only in the detail that is consistent with the available data base.

Work on the Low Freshwater Inflow Study is progressing in accordance with the accepted interactive planning process. This process involves problem identification; the assessment of social, economic, and environmental impacts; the arraying of alternative solutions; and the formulation of a plan. As previously indicated the primary focus of this work is on the relationship between freshwater inflows and salinities. One of the reasons this type of study has rarely been done in the past, however, has been the difficulty of accurately determining this relationship because it can be accomplished only with the aid of tools which can simulate or reproduce the complex three-dimensional estuarine system. The Chesapeake Bay Model does have this capability. In fact, the only other way sufficient data to conduct this study could be made available would be to collect them from the real Chesapeake Bay; a nearly impossible undertaking. To do this it would be necessary to wait for a drought; and who knows when this will occur? During the drought, the data would have to be collected almost continuously over at least a three-year period. This costly venture would require hundreds of people, boats, and equipment. And finally, there is no way presently available to simulate in the bay the depression in river flows associated with consumptive water use.

On the other hand, a drought or depressed freshwater inflows can be simulated at any time on the Chesapeake Bay Model as can nearly any other hydrologic event. The fact that the model is built to a horizontal scale of 1 to 1000 and a vertical scale of 1 to 100 means that Chesapeake Bay has been reduced to less than eight acres, a manageable size which allows for the ready, relatively inexpensive collection of data. And with a time scale of 1 to 100, one year's data can be collected in a little over 3.5 days. Pictures of the model and the 14-acre shelter housing it are shown in Figures 3 and 4.

HYDRAULIC MODEL TESTS

In order to accomplish the objectives of the Chesapeake Bay Freshwater Inflow Study, it will be necessary to conduct a series of three tests on the hydraulic model, i.e., a problem-identification test, a sensitivity test, and a plan formulation test. Both the problem-identification and the sensitivity tests focus on identifying the magnitude of the problem and determining the relationship between freshwater inflows and salinities. The plan formulation test is oriented to the formulation of minimum acceptable freshwater inflows from each of the major bay tributaries. In each test, a representative variable long-term average tide and a weekly hydrograph of freshwater inflows will be used. Both of these will be controlled by a computer.

The purpose of the problem identification test is to determine baywide salinity levels during a drought of record under both natural flow conditions and flow conditions reduced by projected consumptive losses. This test will be done in two parts. The first, or base part, will focus on establishing the salinity structure of the bay during natural drought conditions and determining the amount of time it takes to recover from a drought to a condition of dynamic normality. This will be done by simulating on the model the three low flow years of the worst drought of record (1964, 1965, and 1966) followed by two years of average freshwater inflow conditions. The second, or future part of the test, will be concerned with the magnitude of change in salinities which would be caused by high consumptive uses of water during a severe drought. As in the first part, a five-year hydrograph of freshwater inflows will be simulated in the model. In this case, however, the natural inflows during the three drought and two average inflow years will be reduced by an amount equal to the unconstrained consumptive losses predicted to occur in the year 2020. A comparison of the data from the base and future parts of the test will yield the changes in the salinity regime resulting from decreased freshwater inflows.

The data from both of these parts will be used as the basis for specifically defining existing and potential problems as they relate to both short- and long-term reductions in freshwater inflows and in ascertaining the environmental, social, and economic consequences of low freshwater inflows. They will also be used as a basis for formulating minimum freshwater inflow criteria.

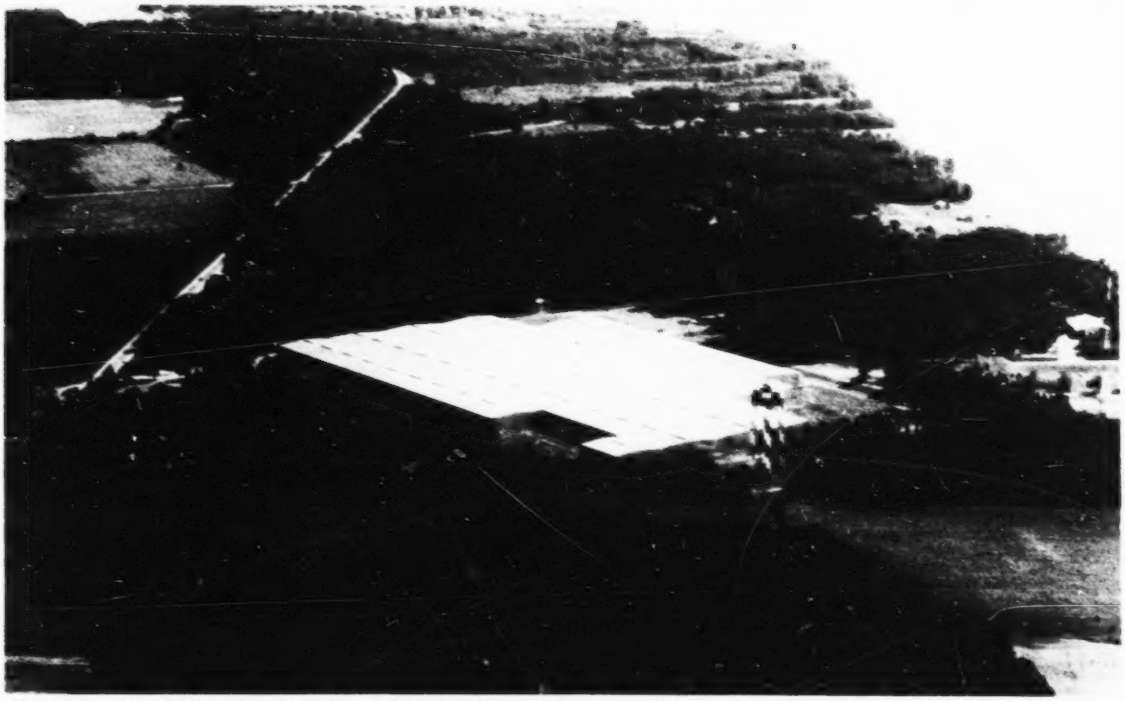


Figure 3 Chesapeake Bay Model Shelter

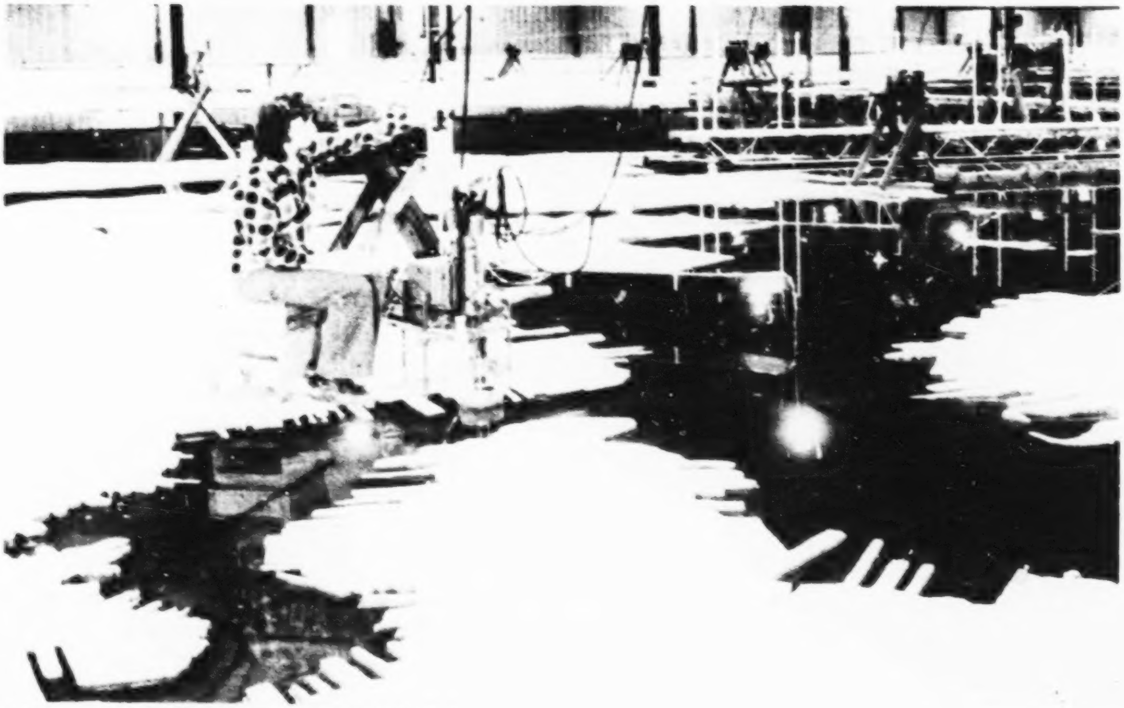


Figure 4 Chesapeake Bay Model

This will be a multi-disciplinary effort involving economists, tidal hydrologists, social scientists, engineers, and biologists. These data will also be important in establishing the relationship between freshwater inflows and salinities in terms of both the effects of various quantities of inflow and the time it takes for salinity levels to respond to changes in flow (reaction time).

It would be difficult, however, to determine from these data the role of each tributary in controlling salinity levels, especially in a geographic perspective. To accomplish this it will be necessary to conduct another series of tests on the model (sensitivity tests). In these sensitivity tests, each major tributary to Chesapeake Bay will be analyzed separately. A one-year hydrograph of the natural freshwater inflows which occurred during the drought of record will be simulated in all tributary rivers except one. In that river, the freshwater inflows will be depressed by anticipated year 2020 consumptive losses. This will be repeated until all major tributaries have been addressed.

The third, or plan formulation series of low flow model tests, will be oriented to formulating a schedule of freshwater inflows for each major tributary which will allow for a healthy biota consistent with social and economic feasibility. The tests to be run will be based on the model tests, impact analyses, and a screening of alternative freshwater inflow levels.

BIOTA ASSESSMENT

A methodology for assessing the impacts of reduced freshwater inflows on the biota of Chesapeake Bay has been developed and is being applied by the consulting firm of Western Eco-Systems Technology (WESTECH) under contract with the Corps of Engineers. In view of the importance of this work, the fact that there is little precedence for it, and the fact that WESTECH is working right at the state-of-the-art, the Chesapeake Bay Study Steering Committee and the Fish and Wildlife Service are intimately involved providing guidance and review of the work as it progressses.

Recognizing that it is impossible to address all of the over 2,700 species that live in Chesapeake Bay, WESTECH developed, through an intensive screening process, a list of over 55 study species. The present known and potential distribution of these species, average salinity, and known substrate were then plotted on maps. These maps will be the basic tool used in the evaluation of the primary impacts of flow changes. Additional maps will be prepared reflecting each set of hydraulic model salinity data. A determination will then be made of the variations in available habitat caused by salinity changes. These habitat variations will be used in assessing the primary biological impacts of flow reductions.

The next step will be the assessment of secondary impacts. This is an extremely difficult task because it involves not only the relationship between salinity and organisms, but the interrelationship among species and families of species. Because a sufficient data base is not available to address these in any great detail, the secondary impact assessment methodology consists of a systems analysis based on a conceptual model and the best available scientific judgments.

PLAN FORMULATION

Social and economic factors also play an important part in the Chesapeake Bay Low Freshwater Inflow Study. An inventory has been made of those economic and social activities which might be affected by changes in freshwater inflows. Examples of these are the withdrawal of water for municipal and industrial use and a potential change in finfish and shellfish harvest which would affect the seafood harvesting and processing sectors. Intensive analyses will be performed relative to all such activities to establish the social, economic, and environmental impact of reduced freshwater inflows.

In conjunction with the environmental, social, and economic assessments a preliminary institutional analysis will be done to survey the existing political, legal and financial structure as it relates to possible implementation of flow criteria. This analysis will focus on the entire Chesapeake Bay Basin.

The next stage of the program will be oriented to formulating and evaluating those alternate flows from the major tributaries which have the potential for alleviating any problems which may be identified. Upstream measures to achieve these flows will also be identified. Such measures may include reservoir storage to augment low flows in the river, conservation measures which produce reductions in consumptive use of water, and policy changes regarding future growth in water-consumption activities.

The biological, economic, social, and institutional impacts of the alternative flows and measures to achieve these flows will be assessed and evaluated, although the upstream analysis will probably be in considerably less detail than the assessment and evaluation of impacts in the bay proper. Based on these analyses, those alternative flows most acceptable under the guidelines provided through the Water Resources Council in its Principles and Standards will be identified and tested during the plan low flow model test. The data from the biological, social, economic and institutional analysis and the final model test will be used in the selection of the schedule of flows to be recommended for each of the major tributaries of the Chesapeake Bay. While a recommended flow schedule will be provided for each of the major tributaries, no recommendation will be made as to the specific upstream measures that should be undertaken to meet the recommended flows. It is anticipated that recommendations for further study of specific upstream alternatives will be included in the final report.

DISCUSSION

Question: Would you care to comment on any other uses that the model over on the eastern shore of the Chesapeake Bay is going to be put to in the near future?

Answer: I'll answer this question in the context of how the Corps of Engineers is using the Hydraulic Model in its studies of Chesapeake Bay. We have formulated a four-year program of tests on the model. The largest component of this program is the Low Freshwater Inflow Test that I have just described. But, we are also looking at other problems that are related to freshwater inflow. One of these is the problem of supplying water to the Washington Metropolitan Area. This area is already water short, and should we have another drought, there could be problems.

My co-workers at the Baltimore District are currently conducting a study oriented to solving this water supply problem. One thing is clear. There are a lot of alternatives. An important one of these is a proposal to use Potomac Estuary at Washington as a supplemental water supply source. There are, however, some questions regarding this proposal. First, although the water at the location where an intake is being considered is normally fresh, the salt wedge intruded to within several miles of it during the last drought. If large quantities of water are withdrawn during one of these droughts, will the salt wedge move far enough upstream to contaminate the water at the intakes? Second, the major wastewater treatment plant for Washington is located about 10 miles downstream from the proposed water supply intake. Will withdrawing water reverse the flow of the estuary sufficiently to cause the wastewater plume to reach these intakes? And third, will withdrawing water during the droughts result in sufficient change in the environment to threaten the integrity of the ecosystem?

In order to assist in answering these questions, we are going to conduct a test on the Chesapeake Bay Model. This test will be in 16 parts. In each part we will simulate a constant flow into the estuary of zero, 250, 500, or 900 mgd, combined with a water supply withdrawal of zero, 100, or 200 mgd. Under each condition, the level of pollution and the salt content of the water will be determined. These data will be input to the social, economic, and environmental analyses that are necessary to determine the feasibility of using the estuary as a supplemental water supply source for the Washington Metropolitan Area.

The water of the Potomac Estuary is already rather polluted and it is anticipated that advanced treatment methods will be required to make it potable. In order to develop these methods, Congress has directed that a pilot treatment plant be constructed. We have already started work on this plant and anticipate that it will be completed next year. At that time, a one-year research program will be instituted.

Last October, the State of Maryland asked us to conduct for them a short test on the Nanticoke River. A large quantity of toxic materials were stored at Sharptown, Maryland, and the state was concerned that they may somehow enter the waterway. Through use of the model, we were able to provide the state with the data needed relative to the fate of any toxic materials that may enter the Nanticoke River.

Another test which will be done for the State of Maryland is related to the dispersion of the thermal plume from power plants. In this test we will simulate the heated discharge from an existing plant and a proposed one. The thermal plume will be monitored over a one-year period to ascertain its rate and extent of dispersion. This test will also directly benefit the Corps of Engineers as the State has already collected some field data, and we can use these data to verify that the model accurately simulates dispersion.

The High Freshwater Inflow Test is one of our more important tests. The objective of this test is to ascertain the impacts on Chesapeake Bay of large influxes of freshwater similar to those which occurred during Tropical Storm Agnes. We intend to simulate on the model three events of this type. Data collection efforts will be oriented to monitoring salinity levels and ascertaining how long the bay takes to return to a state of dynamic normality. These data will be used in assessing the social, economic, and environmental impact of high freshwater inflows.

The latest test in our program is the Tidal Flooding Test. Today, the people of Chesapeake Bay area feel rather secure, as the last large flood was in 1933. Since that time, there has been much development in the flood plain, and if another storm occurred, there could be widespread damage. But, the flood plain of Chesapeake Bay and its tributaries is not that well defined. Our objective is to use the hydraulic model in conjunction with a numerical model to provide a better definition of flood frequency. In this case, our primary tool will be the numerical model. Data from the hydraulic model will be used to assist in calibrating and verifying the numerical model. I might add that conjunctive use of models is becoming increasingly important in addressing hydrodynamic phenomena. There is no question that better answers can be obtained if the numerical model and the hydraulic model are used so that their strengths are accentuated and their weaknesses minimized.

REFERENCES

U.S. Army Engineer District, Baltimore. Chesapeake Bay Plan of Study; June 1970.

U.S. Army Engineer District, Baltimore. Chesapeake Bay existing condition report; 1973. Available from NTIS, Springfield, VA; AD-A005500 thru AD-A005506.

U.S. Army Engineer District, Baltimore. Chesapeake Bay future condition report; 1977. Available from NTIS, Springfield, VA; AD-A052482.

U.S. Army Engineer District, Baltimore. Chesapeake Bay study revised plan of study; October 1978.

Western Eco-Systems Technology. Chesapeake Bay low flow study; Biota Assessment; 1980.

ASPECTS OF IMPACT ASSESSMENT OF LOW FRESHWATER INFLOWS TO CHESAPEAKE BAY

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and D.F. Bleil

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ABSTRACT

Modification of the Chesapeake Bay hydrologic environment has occurred over the past several decades, and is expected to continue at least until the end of the century. An attempt to assess the impact of low freshwater inflows (due to drought and consumptive losses) upon the Chesapeake Bay biota is currently underway. Some of the tools being used in this assessment are 1) distribution, tolerance, and life history studies of selected estuarine species, 2) hydraulic modeling of the bay's salinity and circulation regimes, and (3) computer simulation of representative segments of the ecosystem. The uses and limitations of each are discussed.

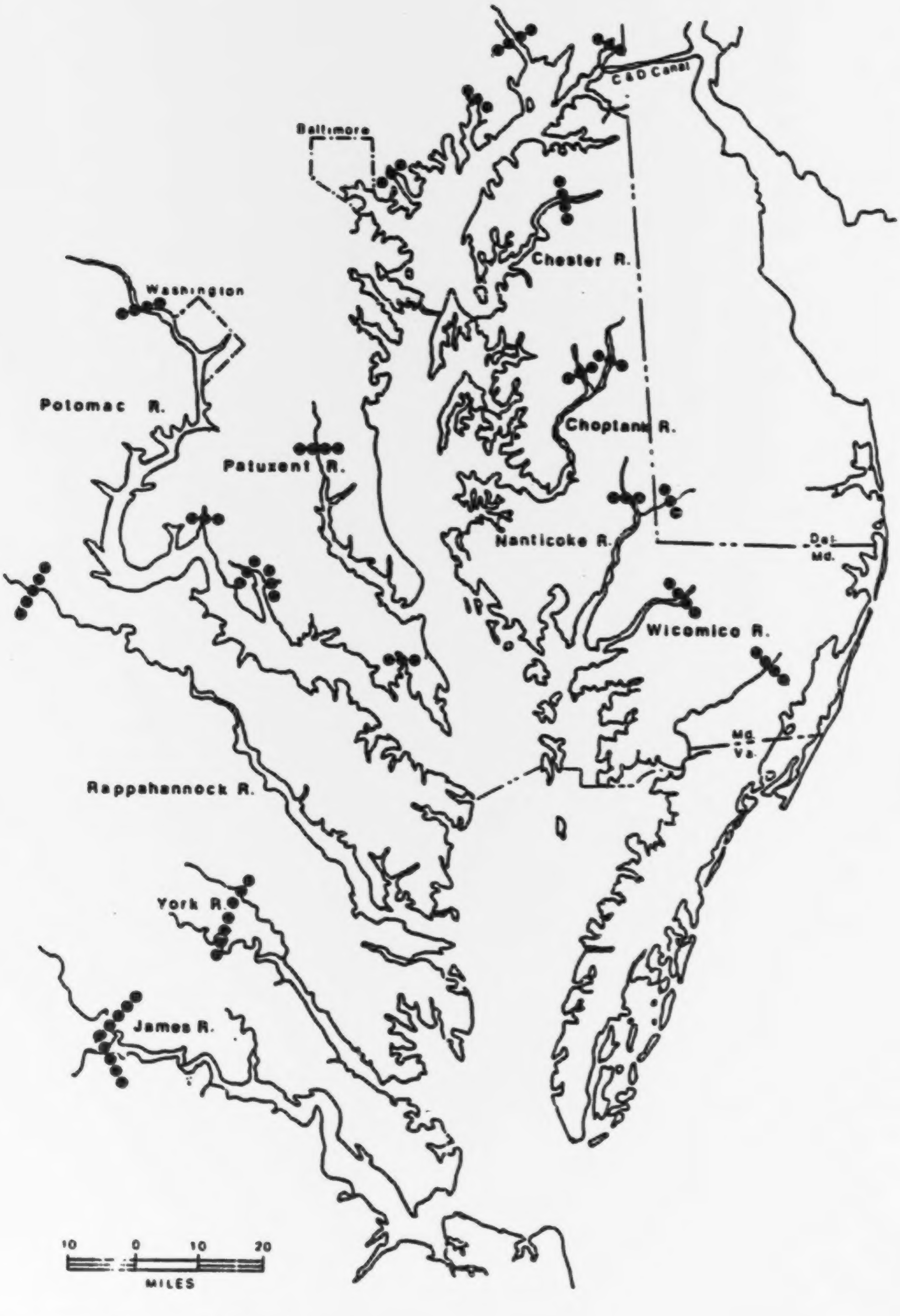
Critical life history stages, habitat and food requirements, and tolerance to physical stress have been used to select representative study species for evaluation of effects of reduced freshwater flows. This approach is limited by the inability of species-by-species analysis to deal adequately with the interrelationships between estuarine organisms. Information on community structure and trophic relationships has been used to develop a conceptual model of major energy flows within the Chesapeake Bay ecosystem. A computer simulation model will be used to provide insight into the effects of low flow, and the propagation of these effects throughout the ecosystem. The results of this study will aid managers in planning consumptive-use patterns of freshwater flows into the estuary.

INTRODUCTION

The U.S. Army Corps of Engineers has, among its responsibilities, that of setting low flows on many Federal water resource projects on regulated rivers. In addition, in 1965, Congress authorized the Corps, under Section 312 of the River and Harbor Act to

> "make a complete
> investigation and
> study of water utilization and control
> of the Chesapeake
> Bay Basin."

This authorization included authority to develop tools to study altered flow conditions including a hydraulic model. The investigation authorized by Congress led to, among many other products, a study of low flows and their impact upon the biota of the Chesapeake Bay and its tributaries. This "Biota Assessment" was undertaken beginning in 1979 by Western Eco-Systems Technology (WESTECH) under the auspices of the Corps of Engineers and is still in progress. The study area extends from the bay mouth to the head of the tide, as shown in Figure 1.


C&D Canal
Baltimore
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Chester R.
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Patuxent R.
Choptank R.
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Wicomico R.
Md.
Va.
Rappahannock R.
York R.
James R.
10
0
10
20
MILES

Source: Md. Geologic Survey,1970

Figure 1. Head Of The Tide In Chesapeake Bay Tributaries

The Biota Assessment is divided into two phases. The purpose of Phase I was to establish base conditions and develop methodologies with which to identify effects of low flow conditions on biological organisms. Phase II, which will begin during the autumn of 1980, will use these methodologies, together with salinity data from the Corps' hydraulic model to make assessments of biological effects during

- a drought comparable to that which occurred during the mid 1960's,
- a period of increased consumptive water loss due to increases in population and water use in the bay area (as predicted for the year 2020), and
- a combination of drought and consumptive water loss (i.e. a drought occurring in the year 2020).

The methods developed to analyze these scenarios are explained in the remainder of this paper.

DEVELOPMENT OF METHODOLOGY

A given factor at the onset of the Biota Assessment of the Chesapeake Bay Low Flow Project was that it be based on the voluminous existing research on the Chesapeake Bay. Research conducted in the assessment was to be aimed toward synthesis and classification of this information and was to derive theoretical methods to increase its usefulness. No new field research was conducted.

LITERATURE SEARCH

The initial tasks included a search and compilation of the literature and establishment of working contact with bay researchers in a wide variety of fields and institutions. The literature search task consisted of a "keyword" computer search of major sources, coupled to a manual search of major journals and the "grey literature," including technical publications of academic institutions and government agencies.

Establish Baselines

The methodology developed during Phase I involved a multiple approach to assessing low flow impacts. This multiple approach included (1) setting a baseline, (2) selecting study species, and (3) defining tolerances for and interactions between those species. These multiple approaches are discussed in this and the following two subsections.

The word "impact" presupposes a change that can be measured. Such measurement requires establishment of base conditions and delineation of change from that base. For an estuary as complex as Chesapeake Bay, knowledge of the state of the system at a given time is severely limited by the difficulty of doing simultaneous studies. Rather, even research on large projects is typically concentrated in a particular tributary or bay-segment. Therefore, baselines were selected from particular time periods best suited to the data.

Physical, chemical and biological baseline periods were selected in order to set base conditions from which to draw data compilations and to serve as a basis for mapping. The physical baseline focused on salinity. The base period selected was

Water Year 1960. Data were drawn from the Chesapeake Bay Institute Salinity Atlas (Stroup and Lynn 1963). Setting the chemical baseline mostly involved nutrients. Data were drawn from USGS files and from large scale data banks from studies conducted at various periods during the 1960's and 1970's. Biological data were similarly selected from a composite of studies during the 20-year period, 1960 to 1980. An attempt was made to put this data into a context which defines the "health and productivity of the estuary;" however, after a discussion with other bay researchers, it became clear that these concepts could be defined only relative to the baseline and not in an absolute sense.

SPECIES SELECTION

Characterization of biological impact in an estuarine system must involve species at all major trophic levels. However, the Chesapeake Bay is estimated to contain over 2,500 species. Clearly some limitation is necessary.

A multi-step process was employed to select species which are both important to the Chesapeake Bay ecosystem and/or are sensitive to low flow effects (Figure 2). Some organisms which are not sensitive to flow changes are too integral a part of the ecological system not to be considered.

From the immense universe of bay species, a list of 167 candidate study species was selected by assessing from the literature the relative vulnerability of any portion of the species' life history to habitat alteration and other criteria. These were then reviewed by the anchor team and Corps Steering Committee. A second screening reduced the list to 81 species, based on availability of detailed literature on stress tolerance and ecosystem importance. The final screening to 57 species was conducted through use of comparison matrices which compiled the sensitivity of each species or any vulnerable life stage to specific habitat alterations (i.e. salinity, food, circulation, and substrate).

The amount and quality of available data, the economic or social value, and the competitive and predatory or trophic relationships were compiled from available literature and discussions with researchers. A weighted ranking system was then employed to identify the most important, most sensitive and best researched of the study species. These species were then used for determination of tolerances, distribution mapping, and conceptual and simulation modeling.

Chesapeake Bay, although a relatively shallow estuary, supports a large variety of species in various habitats. These habitats range from deepwater pelagic zones to beds of submerged or emergent aquatic vegetation (Figure 3). In order to explore the relationships by which organism distributions are controlled by environmental parameters, a classification for habitat types was defined. There have been numerous attempts at estuarine habitat classification (Cowardin et al. 1977) for various purposes. Since the low flow study is mainly focused on salinity, this was chosen as the major variable in the habitat classification system used. We employed a minor modification of the Venice System (Symposium on the Classification of Brackish Waters 1959) in which the mesohaline category was divided into upper-and-lower mesohaline as follows (Figure 4):

Limnetic (tidal fresh water)	0.0 - 0.5 o/oo
Oligohaline	0.5 - 5.0 o/oo
Lower Mesohaline	5.0 -10.0 o/oo
Upper Mesohaline	10.0 -18.0 o/oo
Polyhaline	18.0 -25.0 o/oo
Euhaline	30.0^{+} ^{o}/oo

In addition, we have defined categories of substrate, depth, seasonality (as related to temperature) and modifications of habitat by other organisms. These categories have been placed on base maps from known Chesapeake Bay data bases. Appropriate combinations of categories into the requirements of a particular organism are then used to define that organism's "potential habitat," wherever sampling data are insufficient to define a "known habitat," or area where the organism has been previously identified (see Figure 5).

These habitat systems then were used to form the framework for interpreting information in the literature on salinity tolerances or requirements for salinity, depth, substrate, etc. Salinity tolerances, for instance, were derived for each organism and the appropriate Venice category determined. Organism distribution was defined by a combination of known locations with "potential habitat" derived from the Venice categories and the other parameters discussed above. Locations of the salinity contours necessary were taken from seasonal data from the 1960 water year, largely from the Chesapeake Bay Salinity Atlas (Stroup and Lynn 1963). These have been plotted on 1:250,000 scale maps of Chesapeake Bay, as have categories of substrate, depth, and other habitat variables. Using these base maps, organism distributions have been mapped on 1:250,000 scale mylar overlays for the 57 study species. Examples of such maps are shown in Figures 6 and 7.

ECOLOGICAL RELATIONSHIPS

Low flows cause direct or primary effects on species through physiological responses due to changes in salinity, nutrients, water quality and similar factors. These effects are generally either immediate or occur over a short period of time (i.e. a few days or weeks). In response, species may increase or decline in population, become extinct in the area, or migrate to suitable habitat in other parts of the estuary, if such habitat exists. These shifts in abundance or distribution imply a new interplay of trophic relationships, which we will term here indirect or secondary effects. The time span of such effects may range from several days to several years, or permanently in cases where a new ecological equilibrium is established. In order to investigate these species relationships, conceptual and mathematical models were developed for Chesapeake Bay.

The approach to modeling used in the project is shown in Figure 8. Data from the scientific literature and related sources served as input to define physiological tolerances and constraints. Predator-prey interactions were defined and basic trophic interactions were charted for interrelated groups (i.e. phytoplankton-zooplankton, etc.). These were then integrated and formed the basis for a conceptual model illustrating the major trophic interactions and nutrient flows. The summary version of this conceptual model is shown in Figure 9, using H.T. Odum's energy language to illustrate

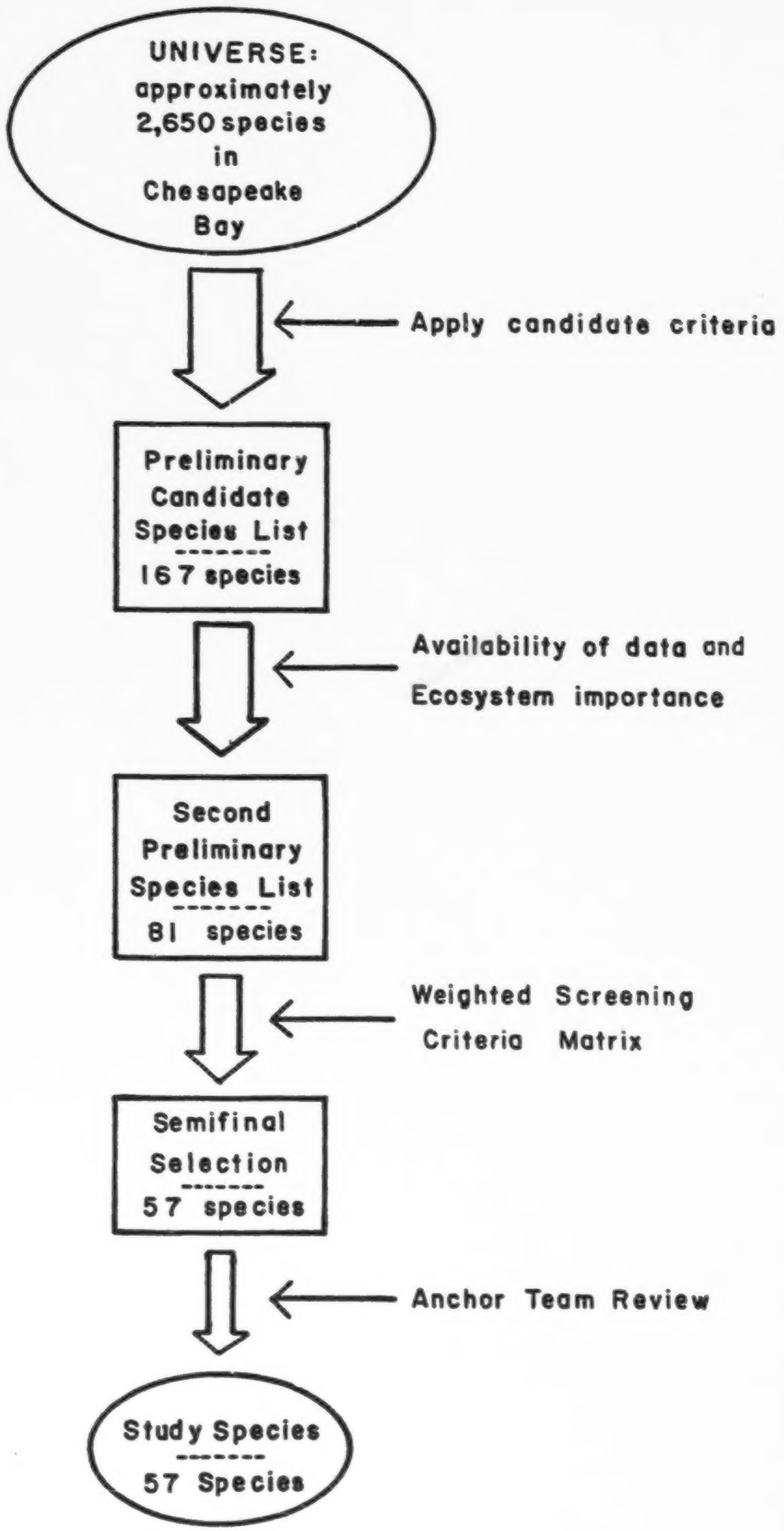

UNIVERSE:
approximately
2,650 species
in
Chesapeake
Bay
Apply candidate criteria
Preliminary
Candidate
Species List
167 species
Availability of data and
Ecosystem importance
Second
Preliminary
Species List
81 species
Weighted Screening
Criteria Matrix
Semifinal
Selection
57 species
Anchor Team Review
Study Species
57 Species

Figure 2 SCREENING PROCESS FOR SELECTION OF STUDY SPECIES

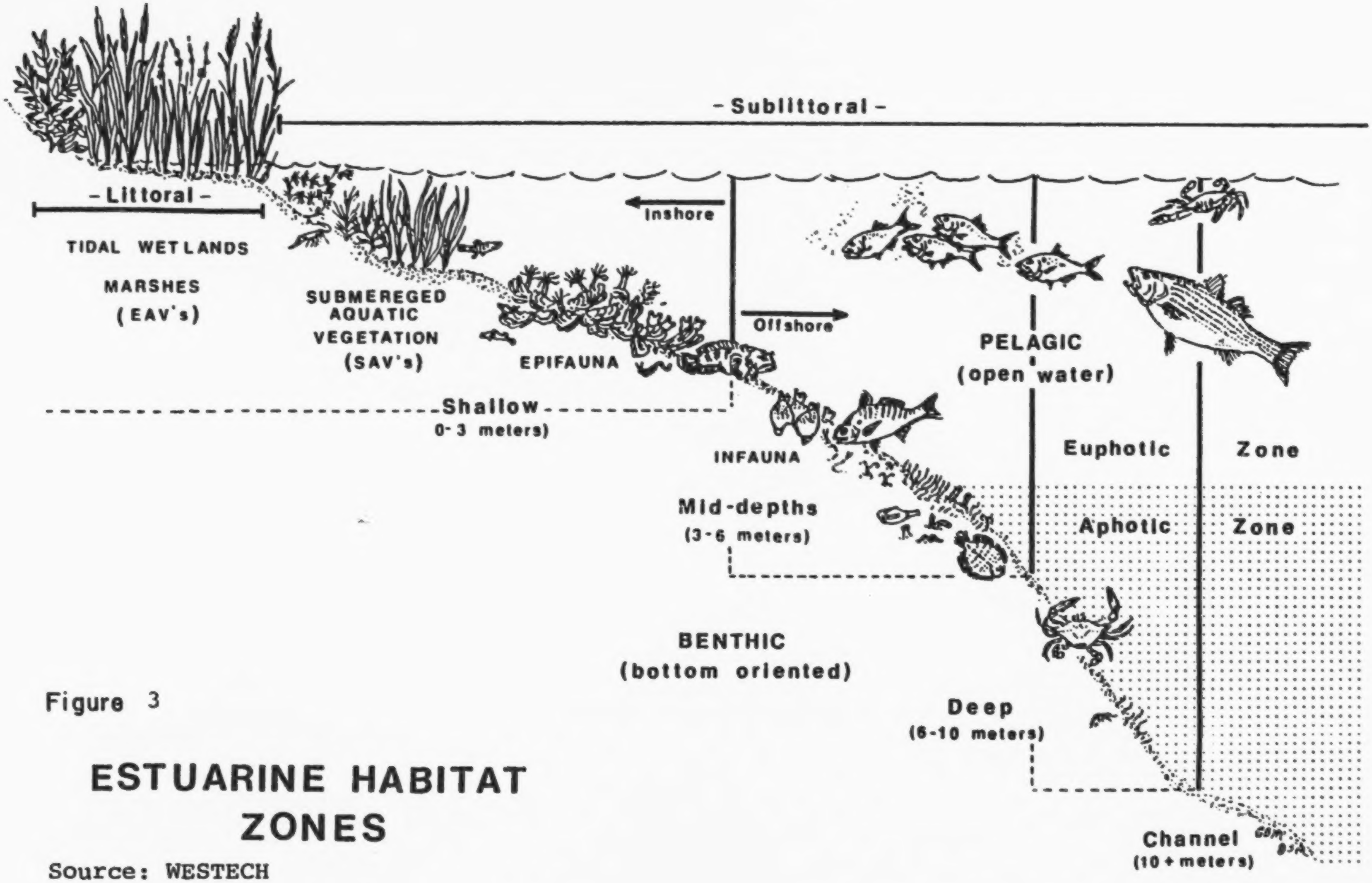

- Sublittoral -
- Littoral -
TIDAL WETLANDS
MARSHES
(EAV's)
SUBMEREGED
AQUATIC
VEGETATION
(SAV's)
EPIFAUNA
Inshore
Offshore
PELAGIC
(open water)
Shallow
0- 3 meters)
INFAUNA
Euphotic
Zone
Mid-depths
(3-6 meters)
Aphotic
Zone
BENTHIC
(bottom oriented)
Deep
(6-10 meters)
Channel
(10+ meters)

Figure 3

ESTUARINE HABITAT ZONES

Source: WESTECH

FALL SALINITY ZONES in the CHESAPEAKE BAY

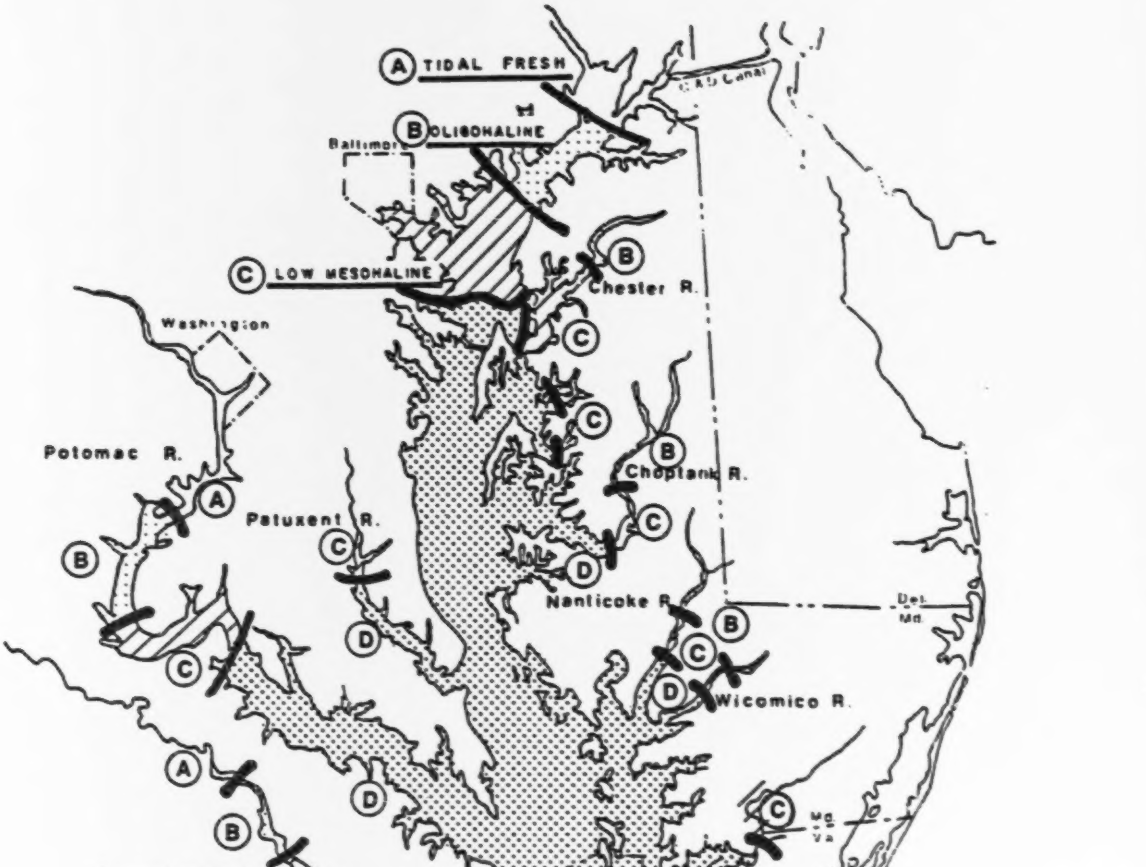

Ⓐ TIDAL FRESH
Ⓑ OLIGOHALINE
Baltimore
C & D Canal
Ⓒ LOW MESOHALINE
Chester R.
Washington
Potomac R.
Patuxent R.
Choptank R.
Nanticoke R.
Del.
Md.
Wicomico R.
Md.
Va.
Rappahannock R.
Ⓓ HIGH MESOHALINE
Ⓔ LOW POLYHALINE
York R.
James R.
10 0 10 20
MILES
Modified Venice System
TIDAL FRESH Ⓐ 0-.5‰*
OLIGOHALINE Ⓑ .5-5‰
LOW MESOHALINE Ⓒ 5-10‰
HIGH MESOHALINE Ⓓ 10-18‰
LOW POLYHALINE Ⓔ 18-25‰

Figure 4

* PARTS OF SALT / 1000 OF WATER

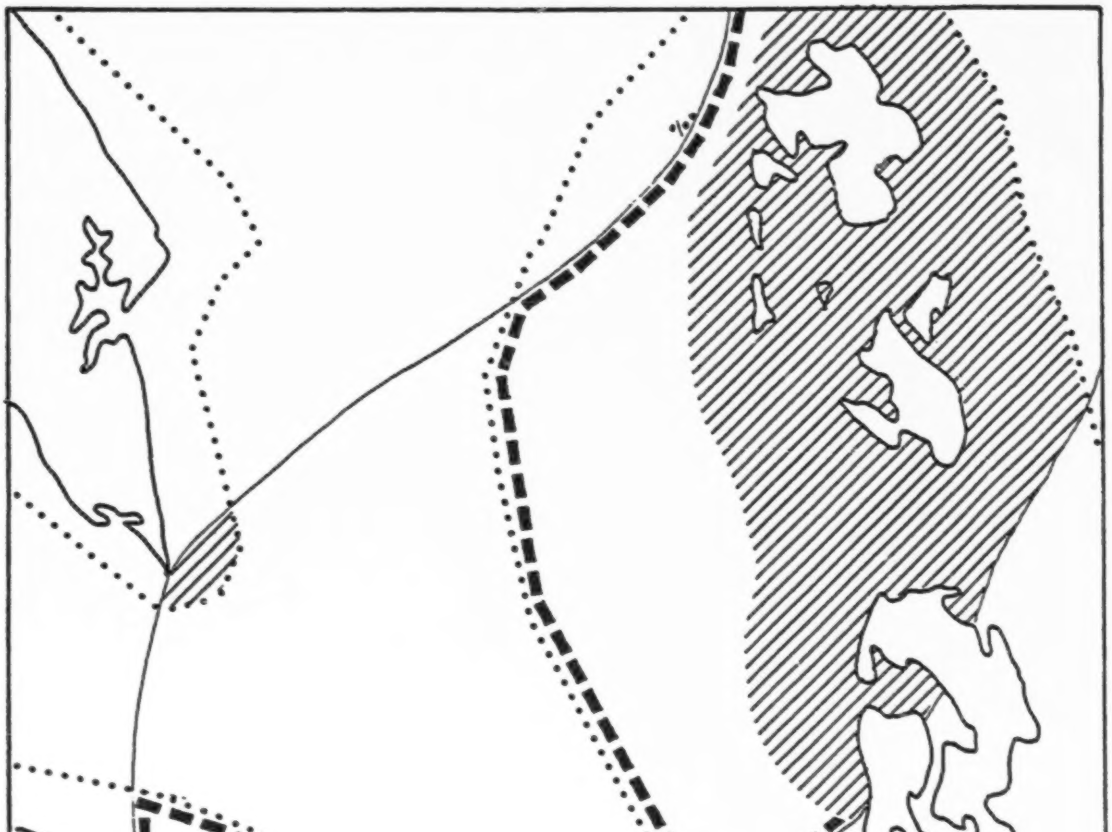

‰
‰
Known Distribution from station data
‰
Isohaline
Substrate Boundary
Potential Habitat based on Salinity and substrate

Figure 5 KNOWN AND POTENTIAL HABITAT OF HYPOTHETICAL BENTHIC ORGANISM BASED ON STATION DATA, SUBSTRATE AND SALINITY

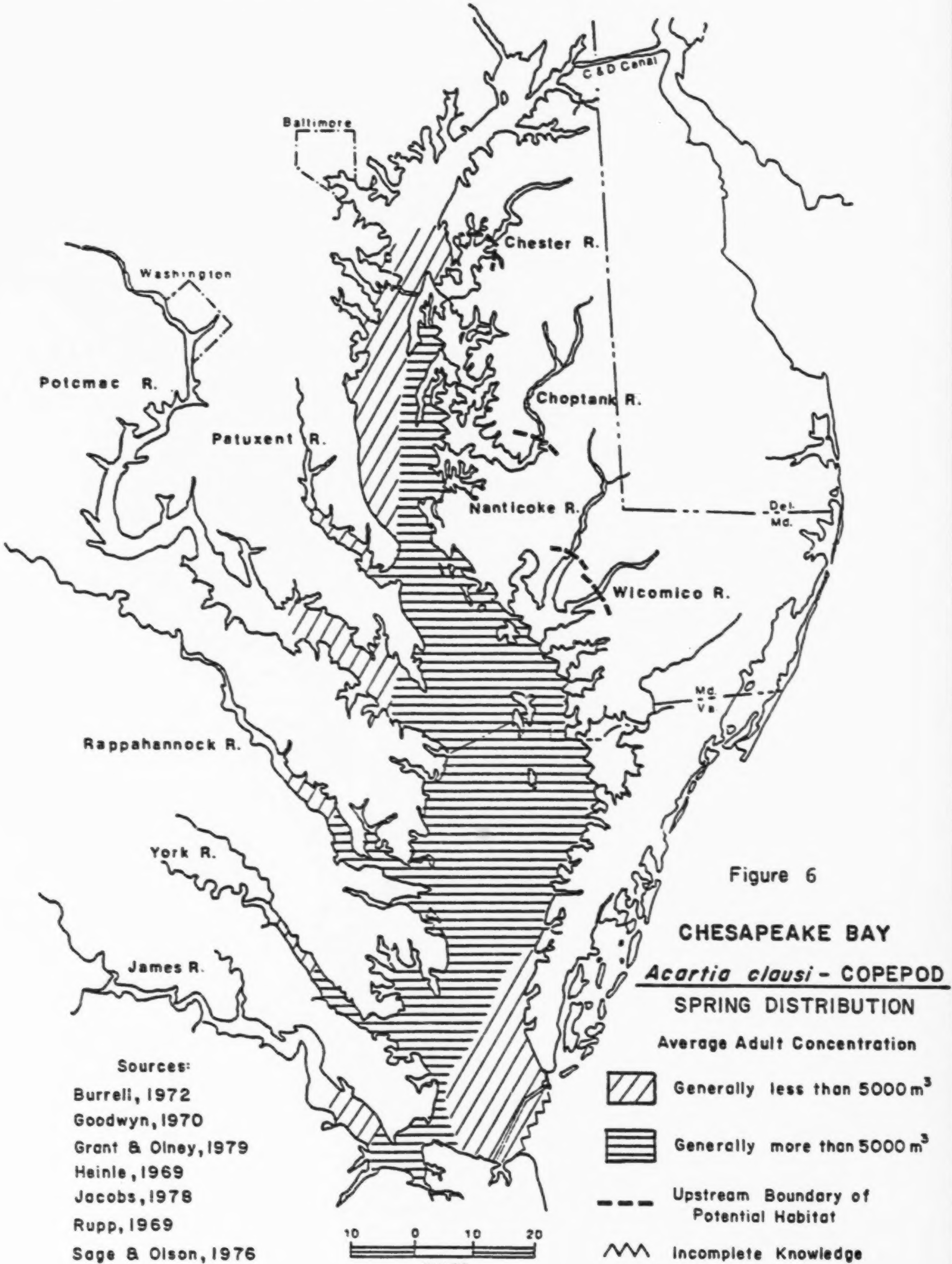

C & D Canal
Baltimore
Chester R.
Washington
Potomac R.
Patuxent R.
Choptank R.
Nanticoke R.
Del.
Md.
Wicomico R.
Md.
Va.
Rappahannock R.
York R.
James R.
10
0
10
20
MILES
Average Adult Concentration
Generally less than 5000 m3
Generally more than 5000 m3
Upstream Boundary of Potential Habitat
Incomplete Knowledge

Figure 6

CHESAPEAKE BAY

Acartia clausi - COPEPOD

SPRING DISTRIBUTION

Sources:

Burrell, 1972
Goodwyn, 1970
Grant & Olney, 1979
Heinle, 1969
Jacobs, 1978
Rupp, 1969
Sage & Olson, 1976
See Text

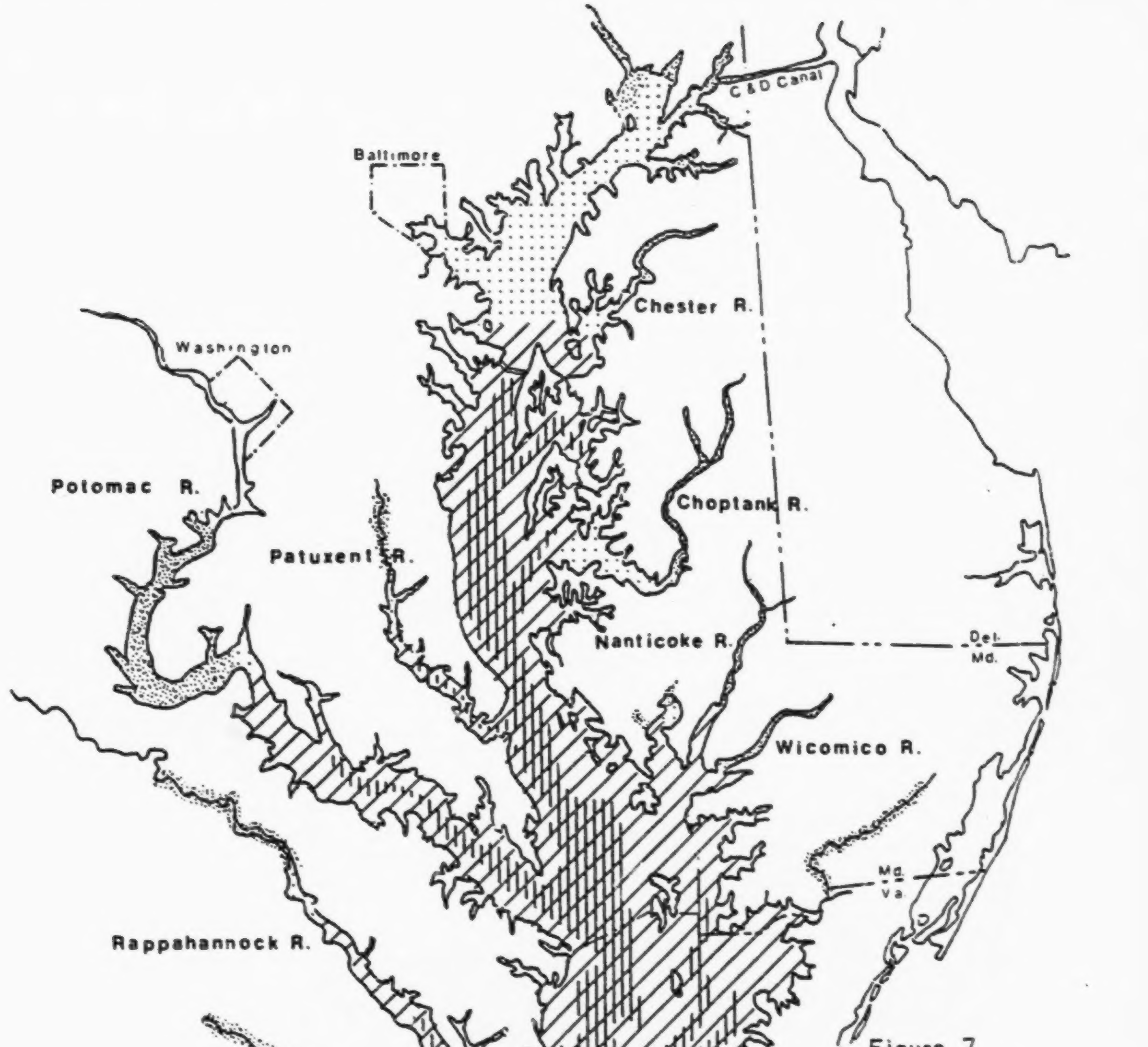

C & D Canal
Baltimore
Chester R.
Washington
Potomac R.
Patuxent R.
Choptank R.
Nanticoke R.
Del.
Md.
Wicomico R.
Md.
Va.
Rappahannock R.
York R.
James R.
10 0 10 20
MILES
Spawning Area – Eggs & Larvae
Juveniles
ADULT & SUBADULT
Summer
Winter

Figure 7

CHESAPEAKE BAY
Morone saxatilis-Striped Bass
DISTRIBUTION
Known and potential Habitat

Sources:
Mansueti & Hollis, 1963
Ritchie & Koo, 1973
Scott & Boon, 1973

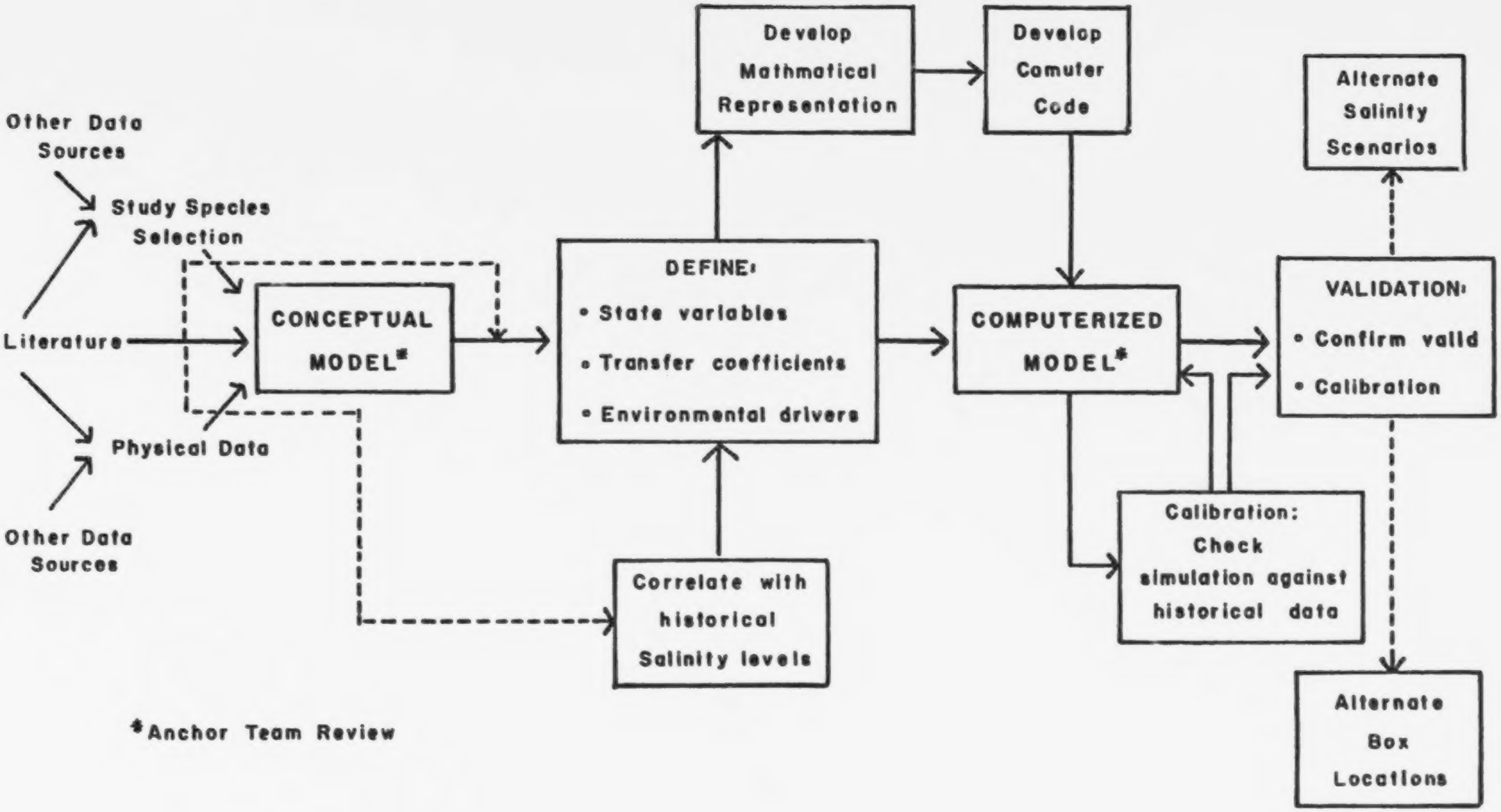

Other Data Sources
Study Species Selection
Literature
Physical Data
Other Data Sources
CONCEPTUAL MODEL*
DEFINE:
• State variables
• Transfer coefficients
• Environmental drivers
Develop Mathmatical Representation
Develop Comuter Code
Correlate with historical Salinity levels
COMPUTERIZED MODEL*
Calibration: Check simulation against historical data
VALIDATION:
• Confirm valid
• Calibration
Alternate Salinity Scenarios
Alternate Box Locations
*Anchor Team Review

Figure 8 APPROACH TO CONCEPTUAL AND COMPUTERIZED MATHEMATICAL MODELING

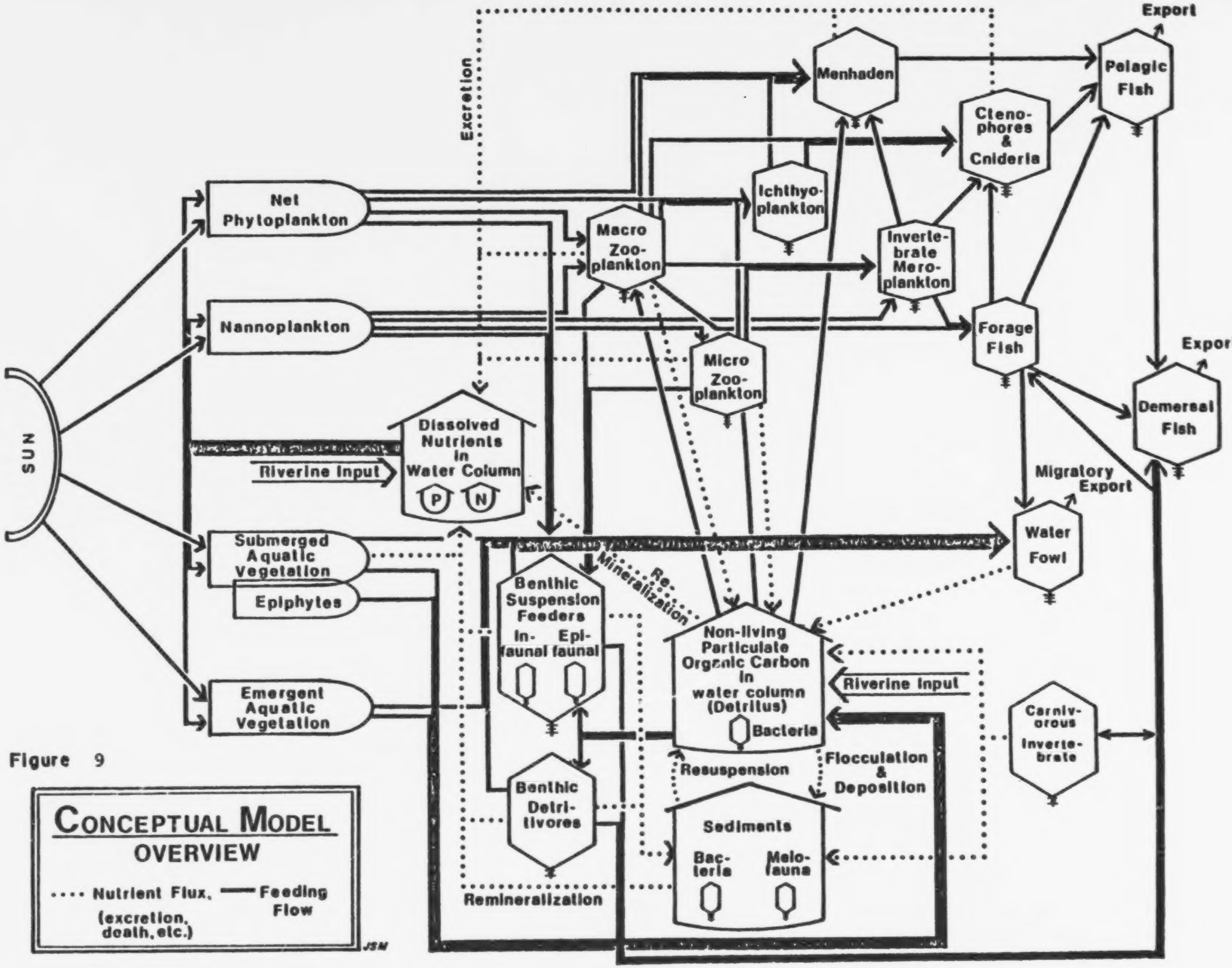


Figure 9

CONCEPTUAL MODEL OVERVIEW

Excretion
Export
Menhaden
Pelagic Fish
Ctenophores & Cnideria
Ichthyoplankton
Net Phytoplankton
Macro Zooplankton
Invertebrate Meroplankton
Nannoplankton
Forage Fish
Export
Micro Zooplankton
Demersal Fish
SUN
Dissolved Nutrients in Water Column
Riverine Input
P
N
Migratory Export
Water Fowl
Submerged Aquatic Vegetation
Epiphytes
Re-Mineralization
Benthic Suspension Feeders
In-faunal
Epi-faunal
Non-living Particulate Organic Carbon in water column (Detritus)
Bacteria
Riverine Input
Emergent Aquatic Vegetation
Carnivorous Invertebrate
Resuspension
Flocculation & Deposition
Benthic Detritivores
Sediments
Bacteria
Meiofauna
Remineralization
···· Nutrient Flux, (excretion, death, etc.)
—— Feeding Flow
JSM

producers, consumers and storage compartments.

A conceptual model of this scope is complex, even in this summary form. Perturbation of the system by a stress, such as low flow, induces many concurrent changes in compartments, functions of organisms and trophic flows. The human mind has difficulty dealing with such simultaneous changes and their ramifications. Computers form a powerful tool for dealing with such systems. Therefore a simulation program (designated Chesapeake Bay Ecosystem Model -CBEM) was created to assist in dealing with secondary effects. This model supplements the conceptual model and provides a tool to analyze the sensitivity of particular species or compartments to low flow effects.

CBEM has been initially defined for the lower mesohaline Venice zones, using data from the Patuxent River, one of the western shore tributaries of the bay. Under average flow conditions, the species and compartments utilized are shown in Figure 10. The system includes phytoplankton as the major producers, grazed by two competitive species of copepod zooplankters. These are grazed in turn by ctenophores during particular time periods. Other feeders include benthic grazers (oysters), juvenile fish and menhaden.

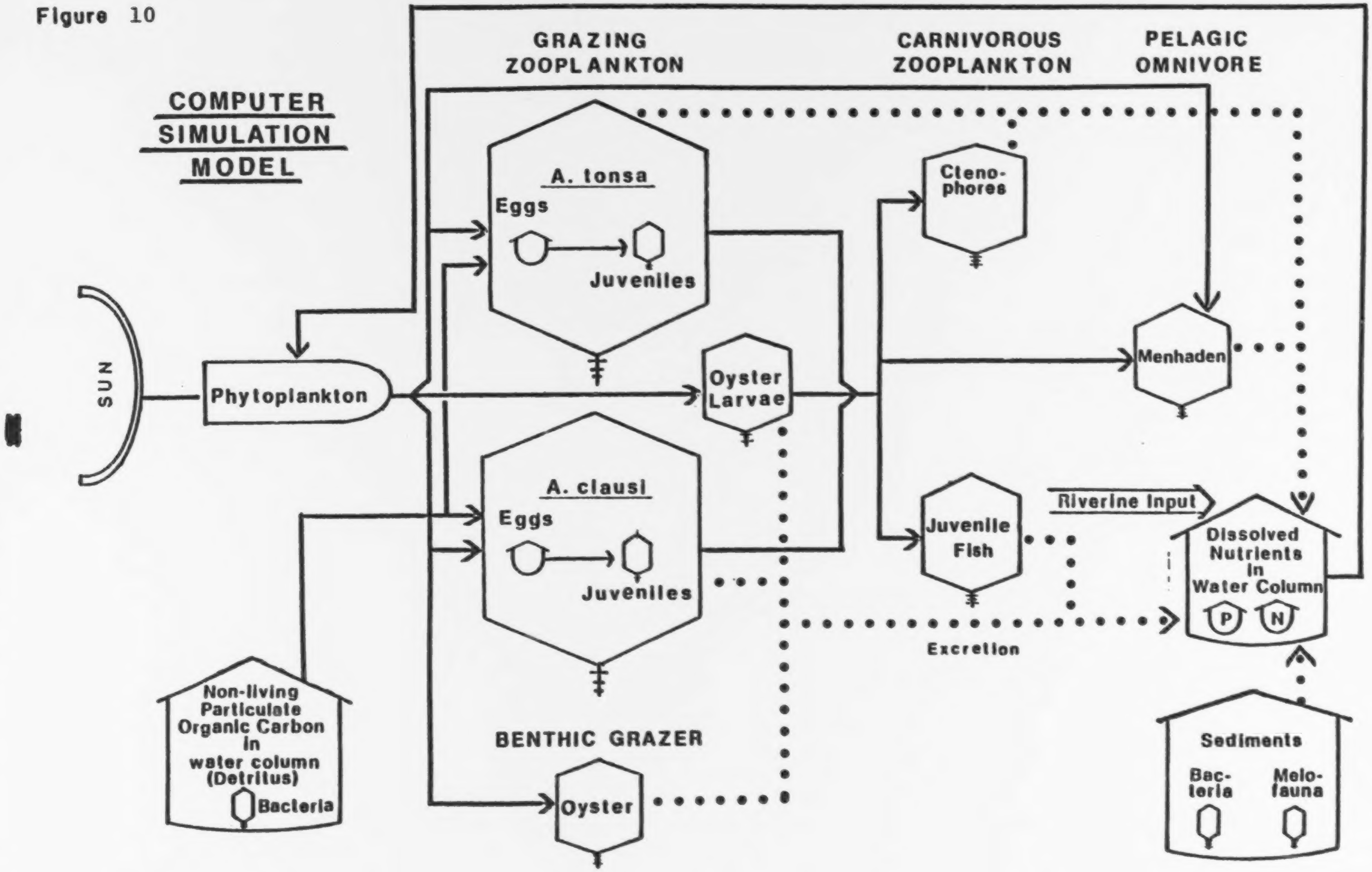
The model is based on sets of quasi-linear differential equations which are periodically corrected to compensate for non-linear behavior in the ecosystem. The model operates by calculating daily productivities and abundances based on changing physical and chemical conditions which can be either input as data or calculated as the program evolves in time. Typical simulated timeframes range from 1 to 5 years for a run. Thus the effects of a low flow period can be tracked for long-term biological changes which occur after the system has returned to a physical or chemical equilibrium.

The model was calibrated with data on known responses and growth rates of organisms, predominantly in the Chesapeake Bay; however, data from other estuaries were used where Chesapeake data did not exist. Tests of the model's validity under average flow conditions were then made, using existing historical data from the Patuxent River, which had not been used to create or calibrate the model. An example appears in Figure 11 for phytoplankton abundance. The figure shows that, in general, simulated phytoplankton abundance agrees well with observed data, although there is a fall bloom in the simulation which is not typically manifested in the data. Knowledge of such discrepancies prompt investigation of biological properties of the ecosystem which might supress or mask such a plankton bloom.

The effects of predation, and the usefulness of CBEM as a tool to study predation effects are illustrated in Figure 12. The changes may differentially affect several other species in the food web, and often are manifested quite differently at times throughout the year as population abundances, growth potential, and feeding behavior are altered.

The main usefulness of both conceptual and mathematical models is to study effects of low flows, particularly those associated with salinity changes. Average annual stream flow into Chesapeake Bay has historically ranged from lows near 50,000 cfs to highs near 150,000 cfs, a dramatic range of values, particularly as it impacts salinity and water quality. Figure 13 shows two

Figure 10


COMPUTER
SIMULATION
MODEL
GRAZING ZOOPLANKTON
CARNIVOROUS ZOOPLANKTON
PELAGIC OMNIVORE
SUN
Phytoplankton
A. tonsa
Eggs
Juveniles
A. clausi
Eggs
Juveniles
Oyster Larvae
Ctenophores
Menhaden
Juvenile Fish
Riverine Input
Dissolved Nutrients in Water Column
P
N
Excretion
Non-living Particulate Organic Carbon in water column (Detritus)
Bacteria
BENTHIC GRAZER
Oyster
Sediments
Bacteria
Meiofauna

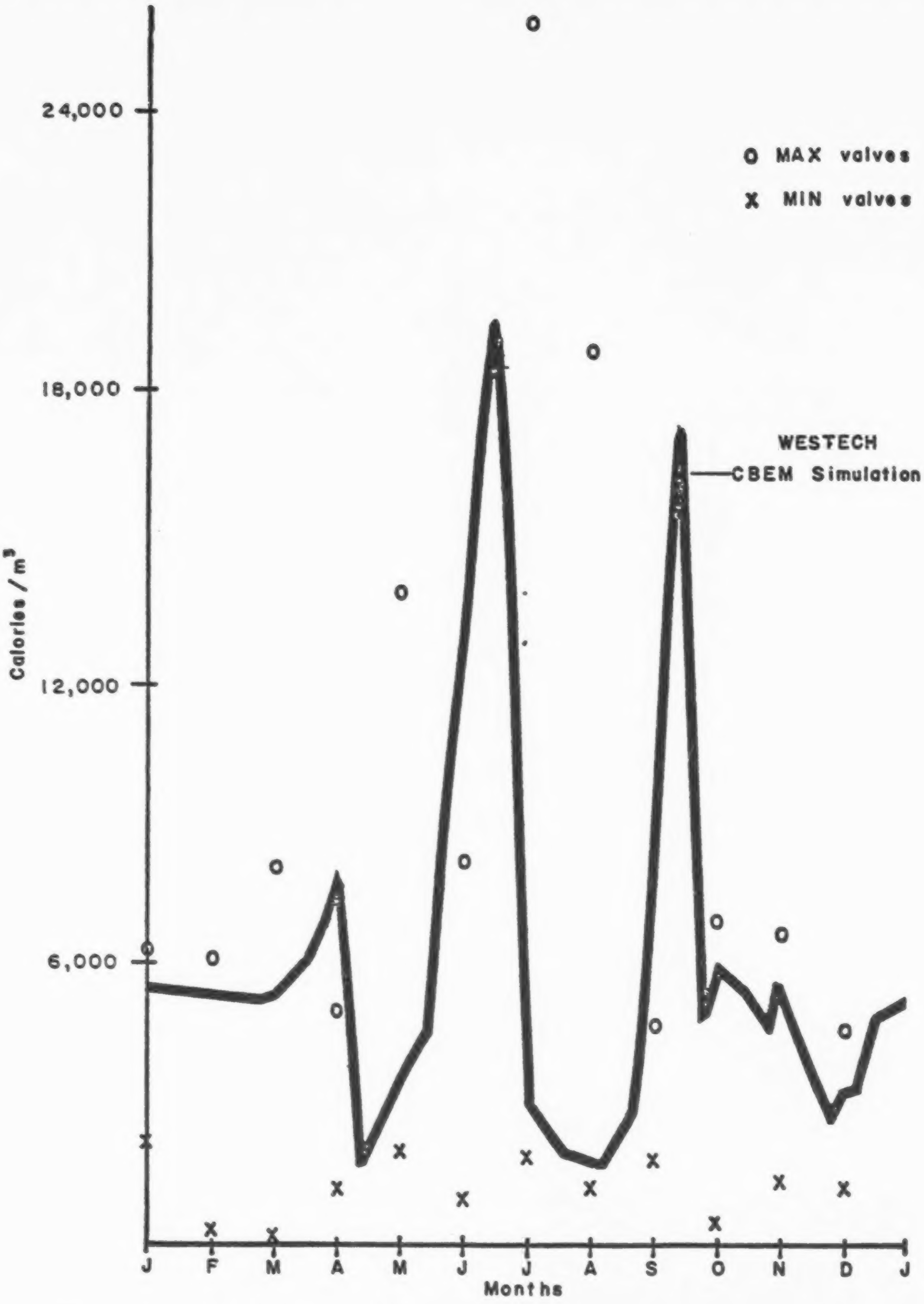


Figure 11 SIMULATED AND OBSERVED PHYTOPLANKTON ABUNDANCE

Sources of observed data: ANSP, unpub., 1975-79; Flemer et al, 1970; Stross and Stottlemyer, 1965

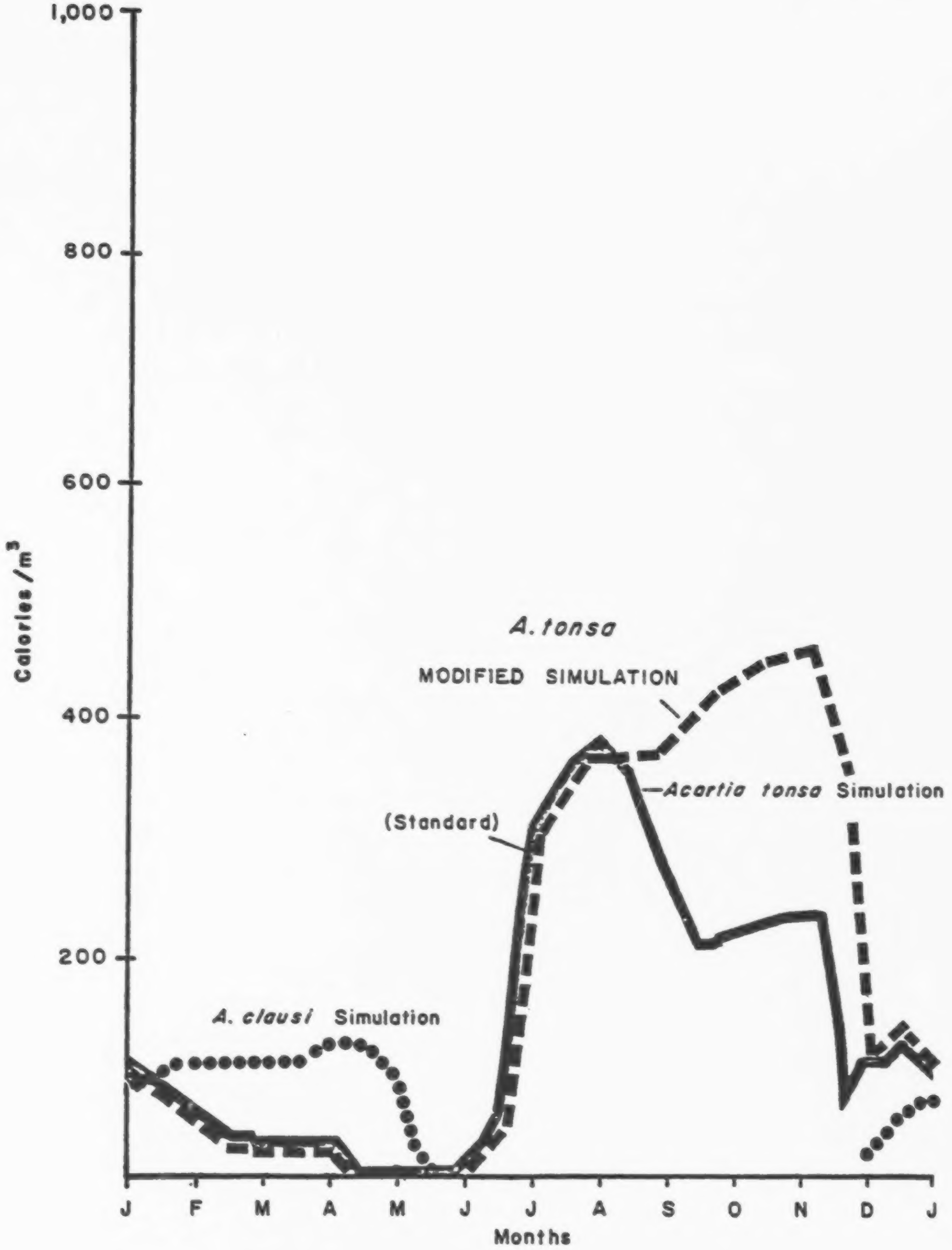
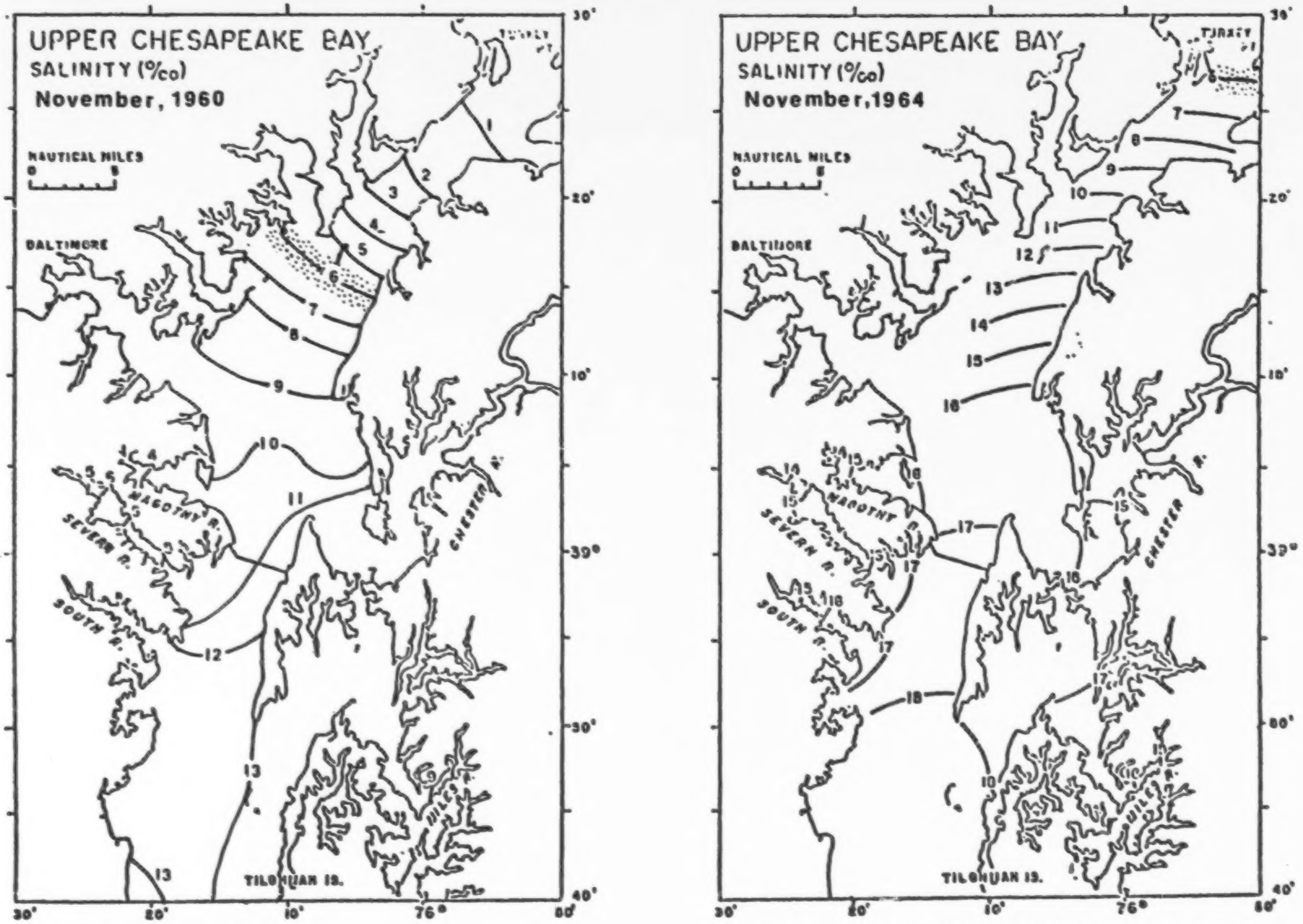


Figure 12 SIMULATED ABUNDANCE OF *Acartia tonsa* AND *A. clausi* WHEN *Mnemiopsis* IS PREDATED AT A DAILY RATE OF 10% (Day 246-365)


UPPER CHESAPEAKE BAY
SALINITY (‰)
November, 1960
NAUTICAL MILES
0 5
BALTIMORE
MAGOTHY R.
SEVERN R.
SOUTH R.
CHESTER R.
MILES R.
TILGHMAN IS.
TURKEY PT.
30'
20'
10'
39°
30'
40'
76°
UPPER CHESAPEAKE BAY
SALINITY (‰)
November, 1964
NAUTICAL MILES
0 5
BALTIMORE
MAGOTHY R.
SEVERN R.
SOUTH R.
CHESTER R.
MILES R.
TILGHMAN IS.
TURKEY PT.

A. Salinities, Base year

B. Salinities, after low-flow period of summer and autumn

Figure 13 CONTRASTING SALINITY DISTRIBUTIONS IN THE UPPER CHESAPEAKE BAY

Source: Pritchard, 1966 ; Stroup and Lynn, 1963 years of contrasting salinity regimes in the upper bay. The species which inhabit the bay are divided into groups with certain tolerances which govern their distribution (Figure 14), ranging from those limited to marine waters, to those limited to fresh water, either for their entire lifetimes or for critical stages such as spawning.

The conceptual or CBEM models can be used as tools to study the effects of new organisms introduced into a given segment of the bay or tributary as salinity regimes change. For instance, CBEM has been run under conditions of higher salinity simulating low flow conditions in the Patuxent. The simulations involved the introduction of predators such as the sea nettle, which are not normally present under average flow conditions. Other factors such as respiration changes, abundance changes, etc. were also altered to conform to the expected changes due to low flows. The biological interactions which were then observed were checked against data from higher salinity zones and some data from a previous drought period and shown to be within a reasonable range of values for such conditions.

Obviously, such ecological modeling has many limitations. Its usefulness is limited by the validity and completeness of the input data base (which for many estuaries is not particularly good). It is also limited by the number of simplifying assumptions that must be made. However, we believe CBEM provides an effective tool for better understanding the complex dynamic interactions which occur under estuarine conditions.

APPLICATION OF METHODOLOGIES

In Phase II of the Biota Assessment, the tools and methods developed during Phase I will be applied to assessing impact of three low flow scenarios based on Corps hydraulic model salinity data. Organism habitats, defined in Phase I for the 57 study species will be analyzed for changes under each low flow scenario. This will be quantified in terms of "impact ratios" which are measures of the change in either known or potential habitat due to salinity alterations. These ratios may be either positive or negative for a particular organism and represent a range rather than a single number, to reflect the inherent inaccuracies in data and gaps in current scientific knowledge of the estuary. These "impact ratios" will measure the direct effects of low flow conditions on individual species.

Indirect or secondary effects which result from species interactions will be expressed quantitatively or qualitatively (as possible and appropriate) utilizing conceptual or simulation modeling as described in the previous section. Quantification of these secondary effects is difficult, particularly in areas where the data base is weak, such as tributaries on the eastern shore of the bay.

SUMMARY

Phase I of the Biota Assessment, a portion of the Chesapeake Bay Low Flow Study, has developed a set of tools and methods with which to assess impacts of low flows. These include

1. Definitions of habitats using uniform variables on a baywide basis.

2. Selection of a set of study species which represent the

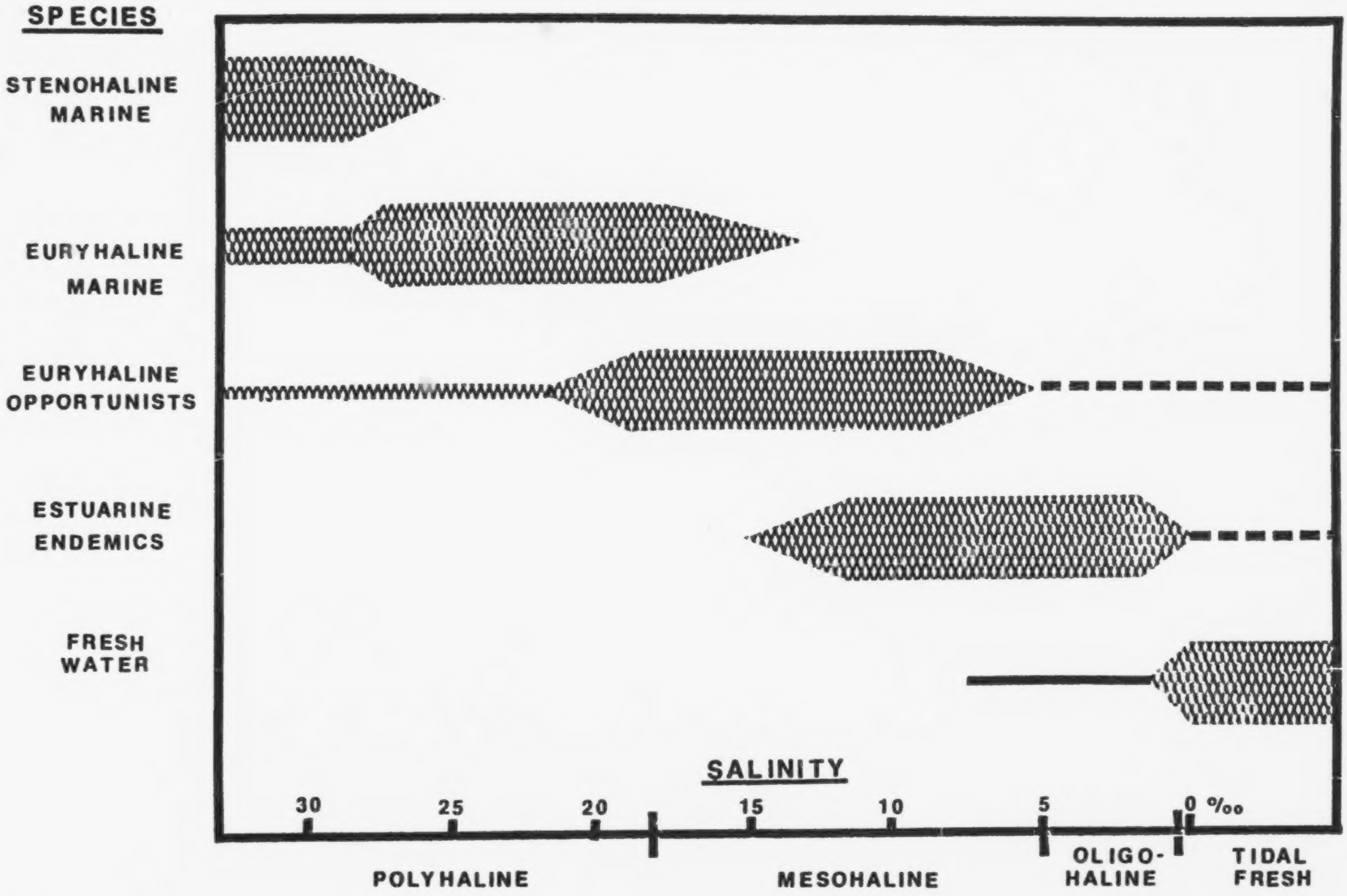


FIGURE 14 ZONATION OF ORGANISMS ALONG THE ESTUARINE SALINITY GRADIENT.

Source: Boesch 1977

main components of the ecological dynamics of the bay.

3. Definition of physical and chemical tolerances and distribution patterns for these organisms (distributions have been produced in a large size map atlas of the entire bay at 1:250,000 scale).

4. Conceptual and simulation models of bay organisms.

These tools will then form the basis for analysis of Corps hydraulic model data representing various low flow conditions during Phase II of the Biota Assessment.

DISCUSSION

Question: (to Dr. Shea) I'm a little curious about this species basis approach to looking at the slough problem in the Chesapeake. You have identified 57 species you've been working with in terms of their salinity tolerance and how they might respond. I wonder, of these 57 species, how many, for example, were plankton or micro zooplankton or bacteria?

Answer: What happens with that kind of approach--because of what people are conscious of--when you start going at it species by species they will start pointing out things they like to catch or eat or see in the bay. That's where we have species-related data on things like striped bass. Whereas what makes any estuarine system go or operate are things which we can't even recognize as a species. We don't have any data for them. Nobody eats or cares about them on an organism level.

REFERENCES

Boesch, H. F. The ecology of the marine cladocera of lower Chesapeake Bay. University of Virginia; 1977 101 p. Dissertation.

Burrell 1972; Goodwin 1970; Grant & Olney 1979; Heinle 1969, Jacobs, 1978; Rupp 1969; Sage & Olson 1976. Cited in: Shea, G.B.; Mackiernan, G.B.; Athanas, L.C.; Bleil, D.F.; Chesapeake Bay low flow study: biota assessment. Phase I: final report. Laurel, MD: WESTECH; 1980.

Cowardin, L., Carter, M.U.; Golet,F. C.; LaRoe, E.T.; Classification of wetlands and deep-water habitats of the United States. Washington, D.C.: U.S. Fish and Wildlife Service, Department of the Interior; 1977; 100 p.

Mansueti & Hollis 1963; Ritchie & Koo 1973; and Scott & Boon 1973. Cited in: Shea, G.B.; Mackiernan, G.B.; Athanas, L.C.; Bliel, D.W.; Chesapeake Bay low flow study: biota assessment. Plase I: final report. Laurel, MD: WESTECH, 1980.

Maryland Geologic Survey. Water. Baltimore, MD: Maryland Educational Series No. 2.; 1970.

Pritchard, D.W. Observations of Circulation in coastal plain estuaries. Lauff, G.H., ed. Estuaries. Washington, D.C.: Am. Adv. Sci. Publ. 83; 1966.

Stroup, E.D.; Lynn, R.J.; Atlas of salinity and temperature distributions in Chesapeake Bay 1952 to 1961 and seasonal averages 1949 to 1961. Graphical summary report 2. Ref. 63-1, CBI; Baltimore, MD: John Hopkins University; 1963: 410 p.

Symposium on the classification of brackish waters. Oikos 9:311-312; 1959.

FRESHWATER INFLUENCES ON STRIPED BASS POPULATION DYNAMICS

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Chesapeake Biological Laboratory, Solomons, Maryland, and
Martin Marietta Corporation, Environmental Center
Baltimore, Maryland

ABSTRACT

A population dynamics study of striped bass (Morone saxatilis) was conducted in the Potomac Estuary from 1974-1977. Investigations included measurements of hydrodynamic characteristics; water quality; phytoplankton; zooplankton; and striped bass egg, larval, juvenile, and adult stages. Larval and juvenile food habit data were also developed. Biological data indicated that striped bass year-class success, as measured by juvenile abundance, was not closely correlated to abundance of spawning stock, number of eggs deposited or early, non-feeding larval stages. These results suggested that density-independent as opposed to density-dependent mechanisms controlled the erratic patterns of year-class success of this species. Climatic data were compared to available juvenile abundance data for a 25-year period. Strong year-classes were correlated with colder than average winters (December) which were followed by above average spring (April) freshwater runoff to the estuary. Larval food habit studies, coupled with earlier work concerning larval transport suggested that high densities of zooplankton at the time of first larval feeding and the spatial distribution of the spawning stock contributed to larval survivorship and consequent establishment of year-class strength. In order to provide projected freshwater supplies for human activity in the Washington, D.C., metropolitan region a number of engineering devices have been proposed, including upstream reservoirs, inter-connections to existing reservoirs, deep-well additions and advanced waste water treatment and reutilization. A number of the above devices have the potential to change hydraulic regimes in the Potomac. The effects of these changes are discussed and evaluated with regard to maintenance of the striped bass stock.

INTRODUCTION

The striped bass is an important commercial and recreational fish native to the East Coast of the United States. It is an anadromous species that migrates during the spawning season from coastal high salinity areas to the fresh or

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*Contrib. 1024, Center for Environment and Estuarine Studies of the University of Maryland.

slightly brackish spawning grounds in the upper reaches of estuarine systems. Research and management interests in this species have increased markedly in the past decade because of stock declines. Recent bibliographies were produced by Pfuderer et al. (1975), Rogers and Westin (1975) and Horseman and Kernehan in 1976. Early accounts of striped bass life histories were published by Scofield (1931), Pearson (1938) and Merriman (1941). Raney (1952) produced a useful summary of striped bass biology and life history. Synopses of biological data on the striped bass have been developed recently by Smith and Wells (1977), Westin and Rogers, (1978) and Setzler et al. (1980).

The species' natural distribution in coastal North America is from the Alabama River on the gulf coast (Brown (1965) to the St. Lawrence River in Canada (Magnin and Beaulieu 1967). Stocking programs have successfully introduced striped bass along the West Coast of the United States where they are reported to range from Ensenada, Mexico, to the Columbia River, British Columbia (Scofield 1931; Forrester et al. 1972). Striped bass have been introduced and established in numerous inland freshwater systems in the United States (Bailey 1975) and have also been transported to Portugal, Russia, and France (Stevens 1966; Delor 1973). In the middle of their natural East Coast range (Cape Hatteras to New England), striped bass are known to undergo extensive coastal migrations; such migratory activity is rare toward the extremes of their range.

Spawning occurs in the Gulf of Mexico from February through May (Barkuloo 1961, 1970) and occurs progressively later in more northern (Barkuloo 1961, 1970) and occurs progressively later in more northern waters. (Raney 1952, Bigelow and Schroeder 1953, Barkuloo 1970). The Chesapeake Bay system has been identified as the principal spawning and nursery area for striped bass on the Atlantic coast and may contribute as much as 90 percent of recruitment to the fishery in Atlantic coastal waters (Kumar and Van Winkle 1978; Berggren and Lieberman 1978). Within the Chesapeake system, the Potomac estuary contributes about 20 percent of the striped bass stock, based upon commercial landings.

This species is noted for fluctuations in abundance which in turn are attributed to periodicities in dominant year classes. Van Winkle et al. (1979) noted that ..."statistically significant periodicities of approximately 20 year and of 6 to 8 year are common to the time series for most states and regions." They stated further that ..."Since the periodicities are neither very pronounced nor simple, it is difficult to isolate the causative factors, which are most likely to be density-independent environmental factors enhancing survival of the young than intrinsic characteristics of the life cycle of striped bass." (Van Winkle et al., 1979: 54).

There has not been a strong year-class of striped bass produced since 1970 on the East Coast and the yield from the fishery has declined markedly. As a result, substantial concern has been expressed and it has been suggested that contaminants are now limiting striped bass success. The effects of heavy metals and petrochemicals upon striped bass are currently being investigated (Whipple et al. 1979). The reauthorization of the Anadromous Fish Conservation Act (PS96-118) by the Chaffee Amendment provides for an emergency 3-year study of striped bass populations. This new amendment recognized that "this species is experiencing a grave crises" and calls for two major efforts: (1) to monitor the status of existing populations, and (2) to identify factors responsible for the decline in stocks. The major emphasis of the former deals with describing egg, larval, and juvenile stocks, while the latter deals with toxicological investigations.

While contaminants may be important factors in some areas, we hypothesize that in the Potomac Estuary extrinsic climate factors in combination with spawning behavior largely determine year-class strength. Our purpose here is to present data in support of this hypothesis and to speculate on possible impacts on striped bass stocks related to changes in the volume and timing of freshwater discharges.

POTOMAC ESTUARY STUDY

The Potomac Estuary (Figure 1), a subsystem of the Chesapeake Bay, was declared a national estuary by President Johnson. The estuary has been utilized for transportation, recreation, fisheries exploitation and sewage disposal since colonial times. Industrial activity is relatively low compared to most East Coast estuaries. Population growth in the Washington, D.C. metropolitan area, located in the upper tidal Potomac, has been substantial in the last few decades. This growth has caused increased demands for electricity, domestic water supplies and has resulted in the release of increasing amounts of treated-sewage effluent to the upper Potomac Estuary.

As part of the power industry's response to projected electricity demands, a nuclear steam electric station was proposed at Douglas Point on the Potomac Estuary, a location that has been identified as part of the Potomac striped bass spawning grounds (Figure 1). The Maryland Department of Natural Resources, initiated a target species approach to examining the possible damage factor to the striped bass fisheries of the Potomac. The major issue concerned the effect of increased mortality rates of egg and larval stages caused by pumped-entrainment activity of the proposed power plant cooling water system on future fishable stocks. Thus a population dynamics study was conducted between 1974 and 1977 and included investigations of river hydrology, water quality, phytoplankton and zooplankton distributions, and quantitative characterization of the temporal and spatial abundance of egg, larval, juvenile and adult stages of striped bass.

Summarized in Figure 2 are striped bass egg and larval densities typical of all years of our study. Several key points can be made from these time-space depictions. While egg deposition occurred throughout most of the study area, highest egg densities appeared progressively upriver from those areas where spawning was initiated. This pattern was supported by data from adult stock assessment studies (Jones et al. 1978). Secondly, despite an average net downstream transport of several centimeters per second, peak densities of all larval stages persisted through time in the same area of the estuary or showed a slight upstream movement. It appears that the stable position of peak larval densities was the result of the successful recruitment of eggs deposited late in the spawning season at upriver locations. Lastly, there was an abrupt

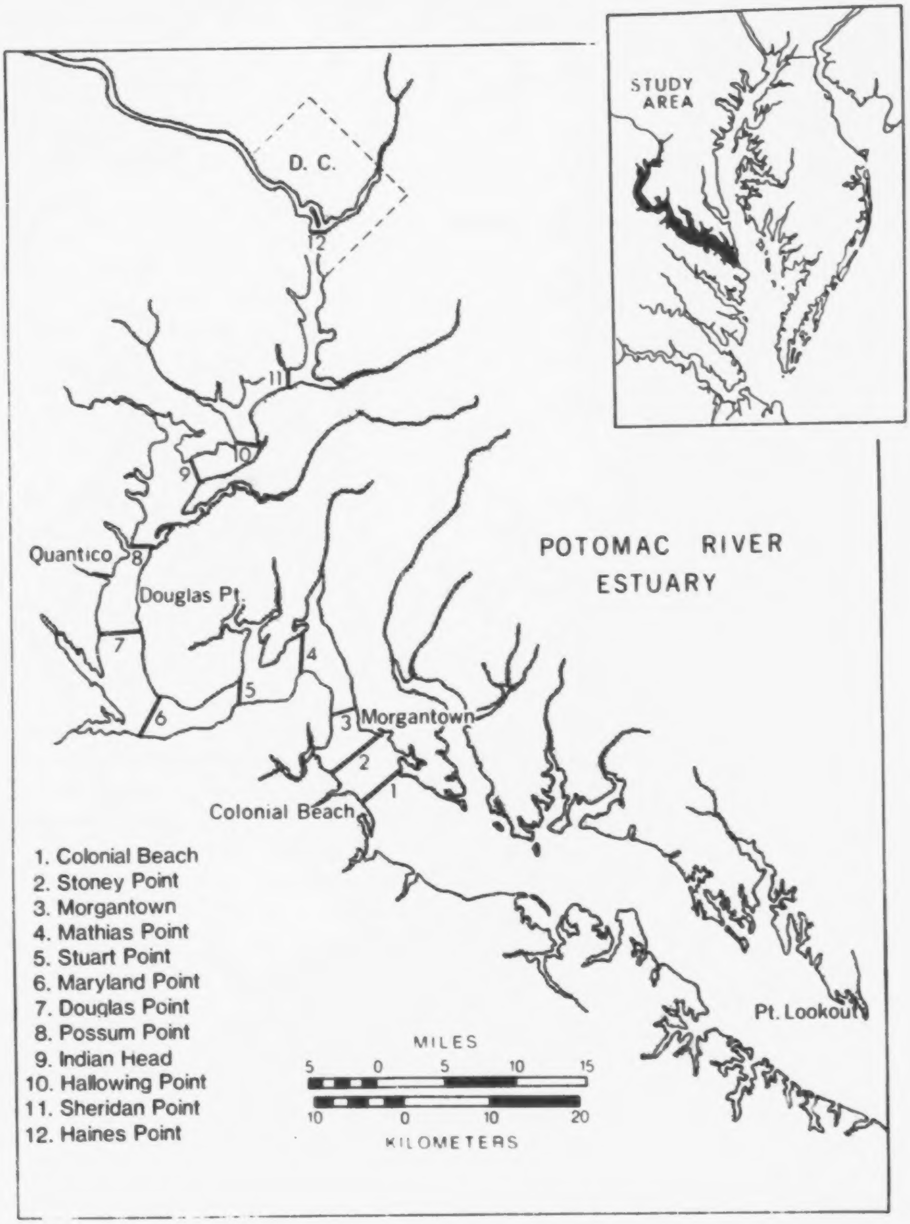
STUDY AREA
D. C.
12
11
10
9
Quantico
8
Douglas Pt.
7
6
5
4
3
Morgantown
2
1
Colonial Beach
POTOMAC RIVER ESTUARY
Pt. Lookout
1. Colonial Beach
2. Stoney Point
3. Morgantown
4. Mathias Point
5. Stuart Point
6. Maryland Point
7. Douglas Point
8. Possum Point
9. Indian Head
10. Hallowing Point
11. Sheridan Point
12. Haines Point
MILES
5 0 5 10 15
10 0 10 20
KILOMETERS

Figure 1. Transect locations for Potomac Estuary striped bass study, 1974-1977. Each transect consisted of from 2 to 6 ichthyoplankton stations which were sampled weekly from April through mid-June with an oblique tow using a 1-m, 505 μm mesh plankton net. Shore stations from transects 3 to 10 were seined by-weekly for juvenile striped bass during the summers of 1975 and 1976. Adult spawning stocks were sampled weekly from mid-March through mid-May with gill nets deployed near transects 3 (1974 only), 6, 8 and 9. The insert shows the location of the Potomac Estuary within Chesapeake Bay. Other major striped bass spawning areas within the Bay include the upper Bay, the Choptank and Nanticoke Rivers on Maryland's Eastern Shore and the James, York and Rappahannock Rivers in Virginia.

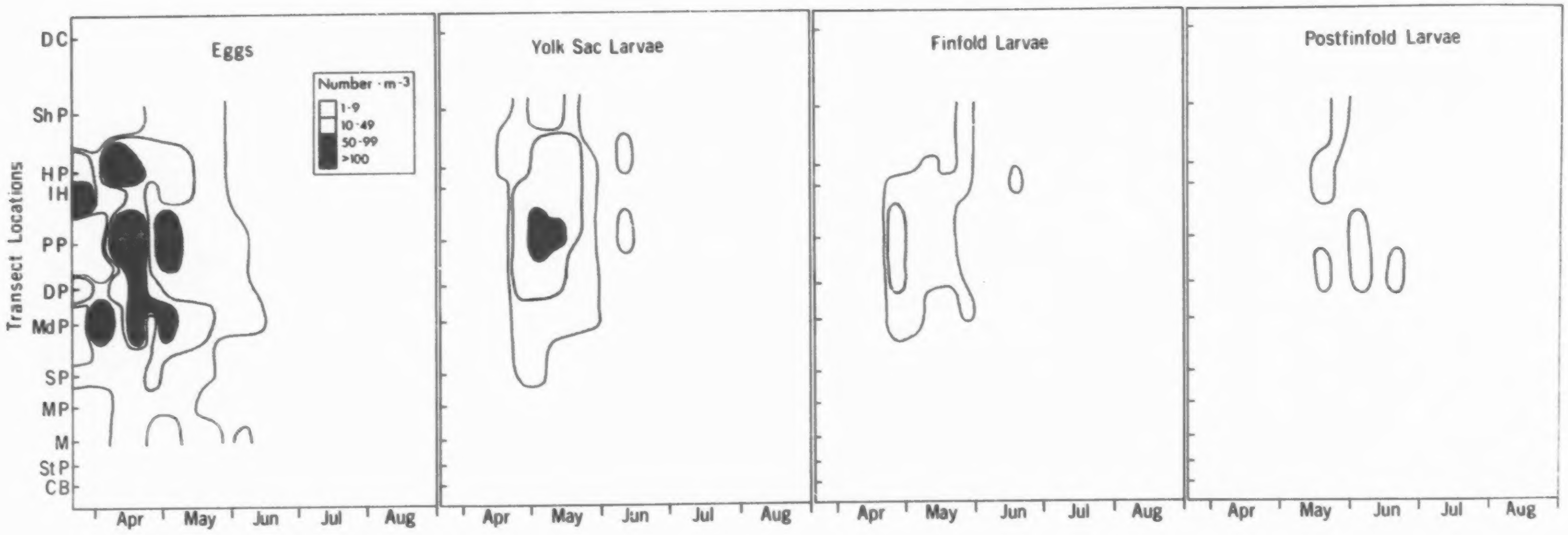

Figure 2. Mean weighted densities (No./m^3) of striped bass egg and larval stages displayed as functions of time and place of capture (Potomac Estuary, 1976). Transect locations were: DC = District of Columbia, ShP = Sheridan Point, HP = Hallowing Point, IH = Indian Head, PP = Possum Point, DP = Douglas Point, Md P = Maryland Point, SP = Stuart Point, MP = Mathias Point, M = Morgantown, StP = Stoney Point, CB = Colonial Beach.

truncation of larval densities beginning in the vicinity of Maryland Point (Md. P.) and extending downstream. This suggested to us, and was later supported by work of Ulanowicz and Polgar (1980), that late stage larvae in this area were subjected to conditions which resulted in higher than normal mortality rates.

Subsequent comparisons of striped bass ichthyoplankton distributions, zooplankton abundances, and food habits of larval striped bass provided evidence which suggested that quantity and distribution of zooplankton in relation to the first larval feeding stages may be a key factor in recruitment success. In a general fashion, larval abundance and the number of food items per larval stomach declined with the densities of food items (zooplankton) in a down-estuary direction (Figure 3). The sharpest gradients in zooplankton densities coincided quite well with sharp declines in late stage larval densities. Moreover, it was found that striped bass larvae fed upon the largest prey items they could capture. Using Jacobs' (1974) modification of Ivlev's Electivity Index:

$$D = \frac{r + p}{r+p - 2rp}:$$

where D is the selectivity index, r is the proportion of a given food type in the feeder ration, and p is the proportion of the same food in the zooplankton, larval striped bass showed a positive selection for adult *Eurytemora affinis*, cyclopoid adults and copepodites, and the cladoceran, *Bosmina longirostris* and a negative selection for copepod nauplii and most rotifer species (Table 1). Since the abundance of the favored-prey species was similar to the general zooplankton abundance pattern, Beaven and Mihursky (1979) concluded that food may have been limiting for striped bass larvae in the lower reaches of the spawning area.

ENVIRONMENTAL INFLUENCES IN RECRUITMENT SUCCESS

To this point, we have built a case which suggests that recruitment success is determined by the end of the larval stage and that position in the estuary where spawning takes place and zooplankton abundance are important factors regulating this process. In this section we attempt to show that these factors are in turn influenced by several climatic variables.

Several authors have successfully related internal ecosystem characteristic to the behavior of extrinsic variables (Menzel et al. 1966, Aleem 1972). Copeland (1966) found that fishery yields in some Texas bays increase in years of above average river flow. Menzel et al. (1966) showed similar trends for oyster stocks in Apalachicola Bay, Florida. Heinle et al. (1975) concluded that colder than normal winters enhance zooplankton and juvenile fish recruitment in the Patuxent River, Maryland. Sutcliffe et al. (1976) and Sutcliffe et al. (1977) demonstrated significant correlations between catches of 17 species of commercial marine fish and shellfish and sea temperatures in the Gulf of Maine.

More to the point, in the California Delta larger year-classes of striped bass seem to result from

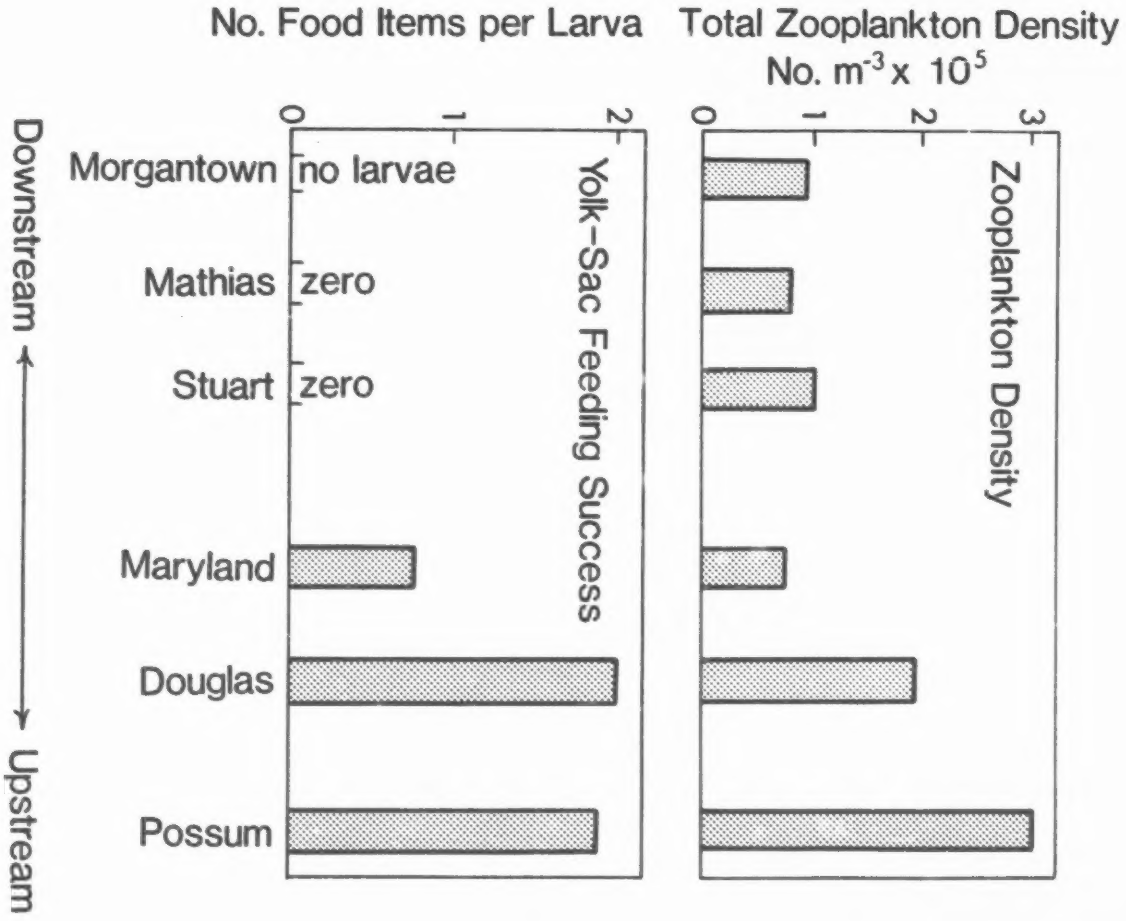

Figure 3. Mean zooplankton density, (No.m^{-3}) and an index of feeding success (No. food items larva^{-1}) Potomac Estuary, May 1976. Zooplankton were filtered from 19 liter water samples collected with a deep-well submersible pump towed horizontally at 1 to 3 m per second. See Figure 1 for transect locations.

Table 1. Mean selectivity index for larval striped bass from the Potomac Estuary, 1978 (from Beaven and Mihursky 1979).

	Larval Stage		
Available zooplankton	Yolk sac	Finfold	Postfinfold
No. of samples from which mean index is calculated	5	4	3
Copepoda			
Eurytemora affinis adults	+0.97	+0.95	+0.97
E. affinis copepodites	-0.21	-0.39	-0.33
E. affinis nauplii	-1.00	-1.00	-1.00
Cyclopoid adults	+0.29	+0.66	+0.56
Cyclopoid copepodites	+0.34	+0.62	-0.42
Unidentified nauplii	-0.95	-1.00	-1.00
Cladocera			
Bosmina longirostris	+0.37	+0.34	+0.31
Daphnia species	-0.10	-0.62	-0.23
Chydorus species	-0.60	-0.75	-
Rotifera			
Brachinous calyciflorus	+0.18	-0.22	-0.81
Brachinous species	-0.46	-0.52	-1.00
Keratella species	-0.70	-1.00	-1.00
Filinia longiseta	-1.00	-1.00	-1.00
Asplanchna species	-1.00	-1.00	-1.00
Polyarthra species	-1.00	-1.00	-1.00
Unidentified rotifer	-0.76	-0.69	-0.87

years of high river flow. Turner and Chadwick (1972) demonstrated that in the Sacramento-San Joaquin System survival of young striped bass (up to 3.8 cm TL) was related to summer river flow through the delta, which controls the transport of young bass to suitable nursery areas. Stevens (1977) and Chadwick et al. (1977) have shown that these river outflows and diversion of river water to the California aqueduct system impact recruitment to the sport fishery several years later and play a major role in controlling the size of the striped bass population. Although years of higher river flow in the California Delta have resulted in large year-classes, virtually all the eggs produced in the early and mid-portions of the spawning season in these high flow years are swept into the lower bays of the delta where survival is extremely low. The mid-summer size distribution of the juvenile fish indicates that they were produced from a small fraction of late spawning fish (Chadwick 1974). Likewise in the Potomac Estuary, striped bass eggs and larvae apparently experience a differential mortality with a greater probability of survival toward the end of the spawning season at the up-river transects (Polgar et al. 1976, Ulanowicz and Polgar 1980, Setzler-Hamilton et al. 1981. Such results would seem to indicate that the production of a successful year-class is largely a density-independent phenomenon, a conclusion first alluded to by Vladykov and Wallace (1952).

We reviewed several climatic data sets in an attempt to identify extrinsic factors which may play a strong role in regulating recruitment success. Such analyses are obviously constrained by the types of data available; in our case air temperature and river flow were readily available and several functions of these were used singly and in combination as predictors of recruitment success. Summer surveys of juvenile striped bass relative abundance have been made in the Potomac since 1958. Recently, this data set has been shown to be a good indicator of both recruitment success (Polgar 1977, Ulanowicz and Polgar 1980) and commercial catch (Boynton et al. 1977) and was used here as the dependent variable in regression analyses. Results of a single factor and multiple factor analyses are summarized in Table 2. In general, statistically significant relationships were indicated for several functions of river flow and air temperature although the percent of the variability explained by the regressions was quite low (about 25%). The percentage of the variability explained using multiple linear regressions was considerably better (about 70%) and in all cases the 5-day maximum flow in April was the strongest predictor. A three-dimensional plot of this regression is shown in Figure 4. Note that all dominant year-classes are clustered in the quadrant bounded by colder than normal winters and greater than normal spring river flows. Additional plots were made using the same temperature function but the highest five-day mean flow occurring in either March or May. Interestingly enough, the previous pattern was not observed suggesting that the timing as well as the quantity of river flow is an important factor in determining recruitment success.

As in all statistical models, significant results or interesting patterns are, per se, incomplete; causation is certainly not demonstrated and for the model to be helpful we need to be able to suggest mechanisms responsible for the statistical results. In our case, we

Table 2. Regression model summary.

LINEAR REGRESSIONS

Independent Variable	Correlation Coefficient	F Value	Degree Freedom	Significance
River Flow				
April 5-day mean high flow	0.51	4.24	1/12	$.10>p>.05$
Total April flow	0.51	4.60	1/12	$.10>p>.05$
March-May (Σ)	0.45	3.08	1/12	$.10>p>.05$
April-May (Σ)	0.40	2.27	1/12	$.10>p>.05$
February-April (Σ)	0.49	3.79	1/12	$.10>p>.05$
March - April (Σ)	0.48	3.73	1/12	$.10>p>.05$
Temperature				
Deviation from mean				
December	-0.50	6.16	1/18	$p<.025$
January	-0.33	2.37	1/18	N.S.
December & January	-0.53	7.10	1/18	$p<.025$
Freeze-Thaw Cycle				
December	0.47	5.36	1/19	p .05
January	-	0.15	1/19	N.S.
November	-	0.09	1/19	N.S

Independent-Variables	r Value
April 5-day maximum flow and December Temperature Deviation	0.84
April 5-day maximum flow and December-January Temperature Deviation	0.82
April 5-day maximum flow and December-February Temperature Deviation	0.79

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[1] Juvenile index is dependent variable

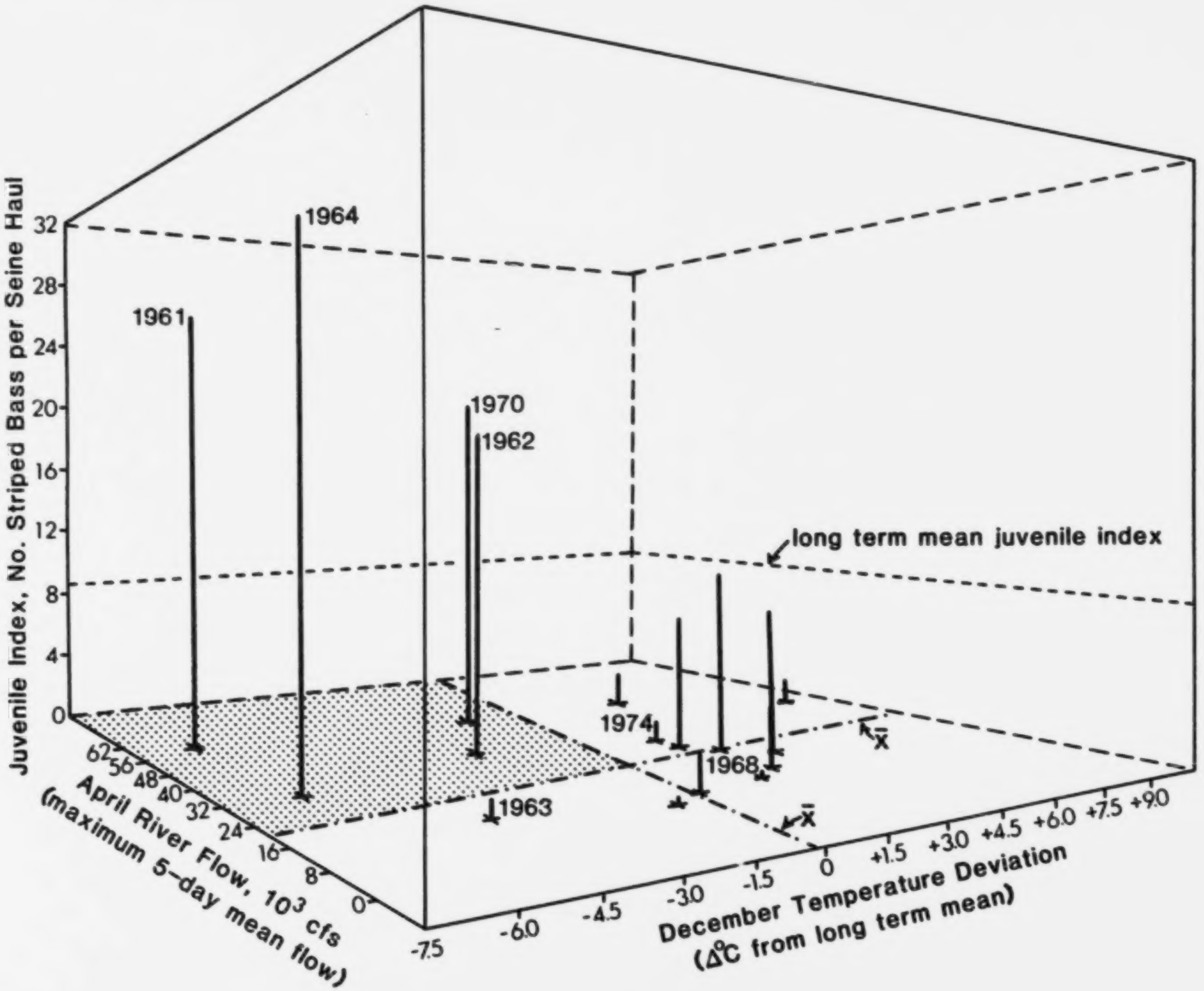

Figure 4. Three dimensional plot of December temperature deviation from long-term average temperatures (± °C), Potomac River flow in April (cfs), and juvenile striped bass abundance index.

currently hypothesize that low winter temperatures act to slow terrestrial losses of detritus and nutrients until the spring thaw at which time these materials are deposited in the river in larger than normal quantities. Heinle et al. (1976) suggested that ice-scour of marshes in the Patuxent River was more complete in cold winters and served as an additional organic matter source for zooplankton which in turn were more available to first-feeding larvae. River flow may act through several mechanisms and, at this juncture, we are uncertain as to the relative importance of these. One concept has it that higher than normal spring flows transport detritus and nutrients to the spawning area in greater abundance than in lower flow years. The enhanced load supports densities of zooplankton at levels appropriate for first-feeding larvae. Another concept extends the first, and suggests that higher than normal spring flows support higher zooplankton densities but also expands the area of the river which has this characteristic. Thus, there is a larger nursery area in which zooplankton stocks are above critical densities for first-feeding larvae (Polgar et al. 1978). An emerging view is that there is always some zone of the upper nursery area which has sufficiently high zooplankton stocks to support some recruitment, even in years of average or low flow. In this view, the key to successful recruitment involves the distribution of spawning adults. Preliminary analyses suggest that certain water temperature patterns in the spring (which are influenced by river flow) act to delay spawning until adult fish have migrated far up into the spawning area. When spawning does occur, emerging larvae have sufficient time to grow through the critical feeding stages prior to being transported out of the rich nursery area. During years of high flow, the areal dimensions of this zone expand. Thus, while we can suggest and, by inference, support several mechanisms, further refinements are obviously needed.

HYDRAULIC ALTERATIONS OF THE POTOMAC ESTUARY

The United States Army Corps of Engineers, in response to legislation requiring the development of water supply plans for major Northeast metropolitan regions, has assisted in developing such a plan for the Washington, D.C. area. The overall program, commonly referred to as NEWS 2020, is the Northeast Water Supply plan to the year 2020.

The Washington metropolitan area obtains the major portion of its water supply from the Potomac River upstream of Great Falls. As given in Figure 5, the minimum low flow recorded was 388 million gallons per day (mgd) on September 1966, while the peak summer withdrawal was 488 mgd on 18 July 1974. A key issue then is the adequacy of river flow to meet demand during low flow periods. Early alternatives suggested were installation of dams on the mainstem river or tributaries in order to withhold spring excess flow and to release this water during summer low flow periods. Subsequent considerations were various water conservation scenarios (Figure 5 and Table 3; Water Forum Notes 1978). Although conservation efforts may reduce projected increase demands, there still remains the possibility of storing a portion of excess spring flows to meet future water needs. If spring flows are critical to striped bass success in the Potomac, it may be that future conflicts will develop

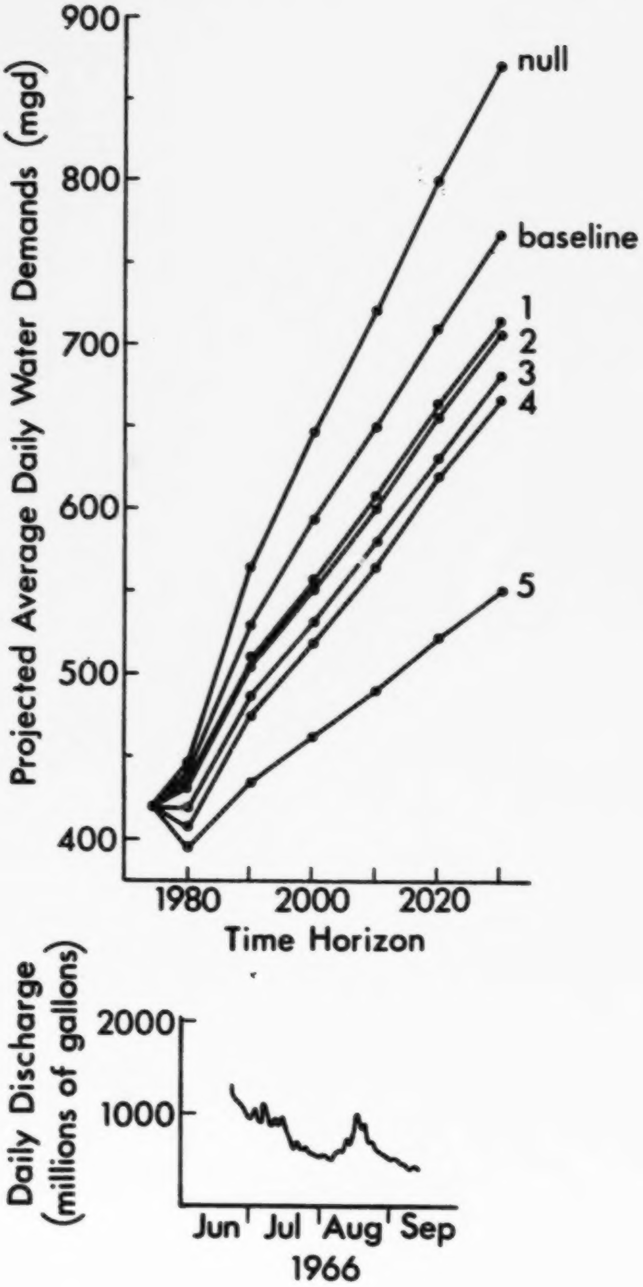

Figure 5. Projected average daily water demands for the Washington, metropolitan area until the year 2030. See Table 3 for explanation of null and baseline projections and projected water demands based on various conservation scenarios. Lower graph depicts daily discharge of the Potomac River at the Washington D.C., gauging station from June-September 1966; the lowest summer flow on record. Peak summer withdrawal for the Washington Metropolitan area was 488 on 18 July 1974; minimum; low flow was 388 mgd on 10 September 1966.

Table 3. Summary of alternate water conservation scenarios for the metropolitan Washington area (from Water Forum Notes 1978).

.Null	-Projection of current rates of water use with no operation changes imposed.
.Baseline	-Projection of current rates of water use with incorporation of current and anticipated metropolitan Washington Area plumbing regulations.
.Scenario 1	-Baseline plus: Additional low water use fixtures to new residential construction, retrofitting water-saving devices to existing residential,
.Scenario 2	-Scenario 1 plus: A reduction in outdoor residential water use achieved through a water conservation educational campaign directed at changing individual water use habits,
.Scenario 3	-Scenario 2 plus: A reduction in indoor and outdoor nonresidential water use achieved through a water conservation educational campaign directed at employees' personal use and management's water use habits,
.Scenario 4	-Scenario 3 plus: A reduction in the unaccounted for water use by minimizing the amount of water lost from leaks through system improvements, and
.Scenario 5	-Scenario 4 plus: The most efficient available low-water use fixtures to indoor new residential and nonresidential; retrofitting water-saving devices to existing residential; a behavior modification to indoor and outdoor, new and existing residential and nonresidential water use; and a reduction unaccounted for water use by minimizing the amount of water lost from leaks through system improvements.

between the need to meet domestic/industrial water supply requirements and flow requirements needed for successful striped bass recruitment and maintenance of fishable stocks. Given the data we have available concerning storage capacity, it is not possible to calculate how much of the spring peak could be placed in storage. In any case, it seems prudent to consider the possibility of storing river water during periods of the year when flow substantially exceeds demand either prior to or after spawning events.

CONCLUSIONS

Intensive sampling of fish egg and larval populations, zooplankton distributions and results of larval stomach analyses indicated that first-feeding larvae represent the critical stage in striped bass recruitment and that high densities of zooplankton are necessary for successful recruitment to occur. Adult spawning stock size is seen to be relatively unimportant compared to factors controlling zooplankton densities and distributions in the estuary. We have tried to build a case which invokes winter temperature patterns and spring river flow as important factors influencing the density and areal distribution of zooplankton and perhaps the migration pattern of adult striped bass. In years having low winter temperatures and high river flow, adult bass appear to move farther up river prior to spawning, possibly due to temperature regulated spawning patterns. Eggs are deposited at the head of the spawning area which has sufficient organic matter resources, due to high freshwater discharge, to support zooplankton populations at densities required by first-feeding larvae. The areal extent of the zone characterized by high zooplankton densities is also enlarged during years of high discharge. Larvae apparently have sufficient time to complete the critical stages prior to being transported out of this zone. The above represents what appears to be a consistent pattern, but one that may nonetheless be modified as analyses continue. Concerning the role of river flow and striped bass success, the case we have built for the Potomac suggests that any significant diminution of springtime freshwater discharge to the estuary would tend to decrease the probability of substantial recruitment success.

LITERATURE CITED

Aleem, A.A. Effect of river outflow management on marine life. Mar. Biol. 15:200-208;1972.

Bailey, W.M. An evaluation of striped bass introductions in the Southeastern United States. Proc. 28th Annu. Conf. Southeast. Assoc. Game Fish Comm. 1974:54-68; 1975.

Barkuloo, J.M. Distribution and abundance of striped bass (Roccus saxatilis, Walbaum) on the Florida Gulf Coast. Proc. 15th Annu. Conf. Southeast Assoc. Game Fish Comm. 1961:223-226

________Taxonomic status and reproduction of striped bass (Morone saxatilis) in Florida. U.S. Bur. Sport Fish. Wildl. 16 p. 1970; Tech. Pap. 44.

Beaven, M.; Mihursky, J.A. Analysis of striped bass larval stomachs. 1976 Potomac Estuary collections final report. Solomons, Md: Univ. Maryland Center for Environmental and Estuarine Studies, Chesapeake Biological

Laboratory; 1979: UMCEES Ref. No. 79-45-CBL.

Berggren, T.J.; J.T. Lieberman. Relative contribution of Hudson, Chesapeake, and Roanoke striped bass, *Morone saxatilis*, stocks to the Atlantic coast fishery. Fish. Bull., U.S. 76:335-345; 1978.

Bigelow, H.B., Schroeder, W.C. Striped bass *Roccus saxatilis* (Walbaum) 1972. Fishes of the Gulf of Maine, U.S. Fish. Wildl. Serv., Fish Bull. 53; 1953; 398-404.

Boynton, W.R., Setzler, E.M.; Wood, K.V.; Zion, H.H.; Homer, Final report on Potomac River fisheries study. Ichthyoplankton and juvenile investigations. Solomons, Md: Univ. Maryland CEES Ref. No. 77-169-CBL. Chesapeake Biological Laboratory, 1977; 328 p.

Brown, B.E. Meristic counts of striped bass from Alabama. Trans. Am. Fish. Soc. 94:278-279; 1965.

Chadwick, H.K. Entrainment and thermal effects on mysid shrimp and striped bass in the Sacramento-San Joaquin Delta. Jensen, L.D., ed. Second workshop on entrainment and intake screening. Palo Alto, CA: 1974; 34 p. (25-30). Elec. Power Res. Inst. Publ. No. 74-049-00-5.

Chadwick, H.K.; Stevens, D. E.; Miller, L.W. Some factors regulating the striped bass population in the Sacramento-San Joaquin Estuary, California, Van Winkle, W,. ed. Proc. of the conf. on assessing the effects of power plant induced mortality on fish populations. 1977; May 3 to 6, Gatlinburg, Tenn. New York: Pergamon Press, 1977; 18-35.

Copeland, B.J. Effects of decreased-river flow on estuarine ecology. J. Water Poll. Control Fed. 38 (11):1831-1939; 1966.

Delor, A. Elevage du bar american *Roccus saxatilis* (Walbaum, 792). I. Metodesutilisees. Sci.Peche, Bull. Inst. Peches marit. No. 224:1-19; 1973.

Forrester, C. R.; Peden, A. E.; Wilson, R.M. First records of the striped bass, *Morone saxatilis*, in British Columbia waters. J. Fish. Res. Board Can. 29:337-339; 1972.

Heinle, D.R.; Flemer, D. A.; Ustach, J. F. Contribution of tidal marshlands to mid-Atlantic estuarine food chains. Wiley, M., ed. Estuarine Interactions, Vol. 2, New York: Academic Press; 1976: 230-309.

Heinle, D.R., and D. A. Flemer. Carbon requirements of a population of the estuarine copepod, *Eurytemora affinis*. Mar. Biol. 31:235-247; 1975.

Horseman, L. O.; Kernehan, R. J. An indexed bibliography of the striped bass, *Morone saxatilis*, 1670-1976. Ichthyol. Assoc.Bull. 12: 118 p.; 1976.

Jacobs. J. Quantitative measurements of food selection. A modification of the forage ration and Ivlev's electivity index. Oecologia. 14: 413-417; 1974.

Jones, P. W.; Wilson, J. S.; Morgan, R. P.; Lunsford, H.R., Jr.; Lawson, J. Potomac River fisheries study; striped bass spawning stock assessment. Interpretive report 1974-1976. Solomons, MD: Univ. Maryland Center for Environmental and Estuarine Studies, Chesapeake Biological Laboratory; UMCEES Ref. No. 77-56-CBL.

Kumar, K. D.; Van Winkle, W. Estimates of relative stock composition of the Atlantic coast striped bass population based on the 1975 Texas Instruments data set. Paper presented at N. E. Fish. Wildl. Conf., Greenbriar, WV, 27 Feb. 1978, Spon. by Am. Fish. Soc.; 1978.

Magnin, E.; Beaulieu, G. Le Bar, Roccus saxatilis (Walbaum), du Fleuve Saint-Laurent. Nat. Can. (Que.) 94:539-555; 1967.

Menzel, R. W.; Hulings, N. C; Hathaway, R. R. Oyster abundance in Apalachicola Bay, Florida, in relation to biotic associations influenced by salinity and other factors. Gulf Res. Rep. 2(2)73-96; 1966.

Merriman, D. Studies on the striped bass (Roccus saxatilis) of the Atlantic coast. U. S. Fish Wildl. Serv. 1941: 1-77. Fish Bull. 50.

Pearson, J. C. The life history of the striped bass, or rockfish, Roccus saxatilis (Walbaum).U.S. Bur. Fish. 825-860; Bull. 49, 1938.

Pfuderer, H. A.; Talmage, S. S.; Collier, B. N.; Van Winkle, W.,Jr.; Goodyear, C. P. Striped bass-a selected annotated bibliography. Oak Ridge Natl. Lab., Environ. Sci.Div.; 1975; 158 p. Publ.615.

Polgar, T.T. Striped bass ichthyoplankton abundance, mortality and production estimation for the Potomac River population, Van Winkle, W., ed. Proceedings of a conference on assessing the effects of power plant induced mortality on fish populations. Gatlinburg, Tenn., 3-6 May 1977. New York: Pergamon Press, 1977.

Polgar, T. T.; Mihursky, J. A.; Ulanowicz, R. E.; Morgan, R. P.; Wilson, J. S. An analysis of 1974 striped bass spawning success in the Potomac Estuary, Wiley, M. L. (ed.), Estuarine Processes, Vol. 1, Uses, stresses and adaptation to the estuary. New York: Academic Press; 1976: 151-165.

Polgar, T.T.; Mihursky, J. A.; Boynton, W. R. Relationship between spawning stock characteristics, environmental influences and spawning success of striped bass in the Potomic estuary. Paper presented at 108th Annual Meeting, American Fisheries Society. Kingston, R.I.; 1978, 22 Aug.

Raney, E.C. The life history of the striped bass, Roccus saxatilis (Walbaum). Bull. Bingham Oceanogr. Collect, Yale Univ. 14(1):5-97; 1952.

Rogers, B. A.; Westin, D. T. A bibliography on the biology of the striped bass, Morone saxatilis (Walbaum). Univ. Rhode Island; 1975; Mar. Tech. Rep. 37. 134 p.

Scofield, E. C. The life history of the striped bass, The striped bass of California, Roccus lineatus. Div. of Fish & Game of Calif.; 1931: 36-60. Fish. Bull. #29.

Setzler, E. M.; Boynton, W. R.; Wood, K. V.; Zion, H. H.; Lubbers, L.; Mountford, N. K.; Frere, P; . Tucker, L.; Mihursky, J. A. Synopsis of biological data on striped bass, Morone saxatilis (Walbaum): 1980; NOAA Technical Report NMFS Circular 433, FAO Fisheries Synopsis No. 121.

Setzler-Hamilton, E. M.; Boynton, W. R.; Polgar, T. T.; Mihursky J. A.; Wood, K. V. Spatial and temporal distribution of striped bass eggs, larvae, and juveniles in the Potomac Estuary. Trans. Am. Fish. Soc. 110:121-136; 1981.

Smith, W. G.; Wells, A. Biological and fisheries data on striped bass, Morone saxatilis (Walbaum). Sandy Hook Laboratory, Northeast Fisheries Center, NMFS, NOAA, U.S. Dept. of Commerce, Highlands, N. J. Tech. Ser. Rep. 4; 1977.

Stevens, D. E. Food habits of striped bass, Roccus saxatilis, in the Sacramento-San Joaquin delta. Turner; J. L.; Kelley, D. W. compilers, Ecological studies of the Sacramento-San Joaquin Delta. Part II. Fishes of the delta, Calif.Dept. Fish Game, Fish. Bull. 136:68-96; 1966.

Stevens, D.E. Striped bass, Morone saxatilis, class strength in relation to river flow in the Sacramento-San Joaquin Estuary, California. Trans. Am. Fish. Soc. 106:34-42; 1977.

Sutcliffe, W.H., Jr.; Drinkwater, K.; Muir, B. S. Correlations of fish catch and environmental factors in the Gulf of Maine. J. Fish. Res. Board Can. 34:19-30; 1977.

Sutliffe, W.H., Jr.; Loucks, R. H.; Drinkwater, K. F. Coastal circulation and physical oceanography of the Scotian Shelf and the Gulf of Maine. J. Fish. Res. Board Can. 33:98-115; 1976.

Turner, J. L.; Chadwick, H. K.; Distribution and an abundance of young-of-the-year striped bass, Morone saxatilis, in relation to river flow in the Sacramento-San Joaquin estuary. Trans. Am. Fish. Soc. 101:442-452; 1972.

Ulanowicz, R. E.; Polgar, T. T. Influences of anadromous spawning behavior and optimal environmental conditions upon striped bass, (Morone saxatilis) year class success. Can. J. Fish. Aquat. Sci. 37:142-154; 1980.

Van Winkle, W.; Kird, B. L.; Rust, B. W., Periodicities in Atlantic coast striped bass (Morone saxatilis) commercial fisheries data. J. Fish. Res. Board Can. 36:54-62; 1979.

Vladykov, V.D.; Wallace, D.H. Studies of the striped bass, R. saxatilis (Walbaum), with special reference to the Chesapeake Bay region during 1936-1938. Bull. Bingham. Oceanogr. Coll. 14(1):132-177; 1952.

Water Forum Notes. Metropolitan Washington Area Water Supply Study, No. 4; Dec. 1978. Baltimore, MD: U.S.Army Corps of Engineers, 1978.

Westin, D.T.; Rogers, B.A., Synopsis of biological data on the striped bass, Morone saxatilis (Walbaum) 1972. Graduate School of

Oceanography, Kingston, RI: Univ. of Rhode Island, Marine Technical Rep. 67; 1978.

Whipple, J. A.; Eldridge, M.; Benville, P.; Jarvis, B.; Bowers, M. The impact of estuarine degradation and chronic pollution on populations of anadromous striped bass (*Morone saxatilis*) in San Francisco Bay-Delta, California. A report submitted to the NOAA, Office of Marine Pollution Assessment, 6010 Executive Boulevard, Rockville, MD; 1979.

EFFECTS OF FRESHWATER FLOW ON SALINITY AND PHYTOPLANKTON BIOMASS IN THE LOWER HUDSON ESTUARY

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ABSTRACT

A two dimensional box model was used to describe variation of phytoplankton biomass in the lower Hudson Estuary under different flow conditions. Both the flux contribution of estuarine circulation and other gain or loss processes are quantified by the model. Lag between gauging data and freshwater flow in the estuary, the vertical structure of current velocity and salinity, and the tidal variation of salinity in each layer were considered in the estimation of model parameters. Results indicate that estuarine circulation was strong and flushing times relatively short under both high and low flow conditions. Biomass fluxes in terms of chlorophyll a were dominated by boundary inputs during high flow and by growth and grazing during low flow. The good agreement found between independent measurements of specific rates and specific rates estimated from the model indicates that the model gives a reasonable description of estuarine phytoplankton processes, and may be applicable in other estuaries.

INTRODUCTION

Phytoplankton biomass variations in estuaries are primarily the result of material fluxes due to estuarine circulation and fluxes due to biological and particulate processes (e.g. growth, sinking, and grazing). Thus fresh water effects on estuarine circulation can be translated to effects on phytoplankton biomass if the relative contribution of circulation-related fluxes is known. In this paper we approach the problem by using models of circulation to make estimates of each flux component during different freshwater flow conditions.

Simple, first order models have been used successfully to study pollutant (Pritchard 1969) and nutrient (Simpson and Hammond unpublished; Taft et al. 1978) distributions in partially mixed estuaries. These models do not include explicitly the dynamics of circulation or details of diffusion processes, but lump all effects into a small number of parameters. A one-dimensional description of the tidally averaged concentration of some property C is given by the advection-diffusion equation:

$$\frac{1}{A}\frac{\partial}{\partial x}\left(EA\frac{\partial C}{\partial x}\;\frac{\partial}{\partial}QC\right)=\frac{\partial C}{\partial t} \qquad (1)$$

A = cross-sectional area
Q = flow rate
E = dispersion coefficient

E includes the effects of upstream bottom advection and tidal mixing. If E is constant with distance and C is constant with time (steady-state), C is exponentially distributed, i.e. $C(x) = C_o \exp(^{Qx}/_{EA}) + C_1$ (1a). This model has been useful in the study of longitudinal salt distributions (Simpson and Hammond unpublished; Stommel 1953), but is of limited use in problems where vertical variations are important (Hansen 1967). This is the case for phytoplankton distributions in the lower Hudson Estuary (Malone et al. 1980) which is partially mixed and characterized by two-layered flow (Abood 1974).

A simple model which incorporates vertical variation is the two-dimensional box model (Pritchard 1969, Taft et al. 1978). In this model the estuary is divided into a series of longitudinal segments and each segment is divided vertically into two layers at the boundary between up- and down-stream net non-tidal flow. Assuming that salinity distribution approximates steady state, and following the notation of Pritchard (1969), the equations defining transport are:

$$Q_{ui} = Q_f\, S_{li}/[S_{li} - S_{ui}],$$
$$Q_{li} = Q_f\, S_{ui}/[S_{li} - S_{ui}] \qquad (2)$$

$$Qvi = Q_{ui+1} - Q_{ui} \qquad (3)$$

where

Q_{ui} = upper layer downstream flow at the i^{th} boundary

Q_{li} = lower layer upstream flow at the i^{th} boundary

S_{ui}, S_{li} = upper and lower layer tidally averaged salinities at i^{th} boundary

Q_f = freshwater flow

Q_{vi} = vertical flow between i^{th} and $(i + 1)^{th}$ boundary

These equations are derived from continuity of salt ($Q_{ui}\ S_{ui} = Q_{li}\ S_{li}$) and fresh water flow ($Q_f = Q_{ui} - Q_{li}$). Defining the mean salinity in the upper and lower layer box between the i^{th} and $i + 1^{th}$ boundary as

$$M_{ui} = \tfrac{1}{2}(S_{ui+1} + S_{ui}),$$
$$M_{li} = \tfrac{1}{2}(S_{li+1} + S_{li}) \qquad (4)$$

continuity of salt in each box is attained by the parameter E_i (vertical exchange) in

$$Q_{ui}\, S_{ui} - (Q_{ui-1}\, S_{ui-1} + Q_{vi}\, M_{li} + E_i\,[M_{li} - M_{ui}]) = 0 \qquad (5)$$

$$Q_{li}\, S_{li} - (Q_{li-1}\, S_{li-1} + Q_{vi}\, M_{li} + E_i\,[M_{li} - M_{ui}]) = 0 \qquad (6)$$

If property 'C' is substituted into Eqs. (4), (5) and (6), Eqs. (5) and (6) define the time rate of change of the amount of 'C' in each box $d\,M_{ui}\,V_{ui}/dt$ and $d\,M_{li}\,V_{li}/dt$, 'V' with appropriate subscripts denotes volume. Dividing through by volume (independent of time to the order of the estimate) and using Eq. (4) to transform equations in 'M' to equations in 'C' defines a matrix equation

$$d\,\underline{C}/dt = \underline{\underline{A}}\,\underline{C} + p\,(t) \qquad (7)$$

C = vector of box boundary property concentrations (upper and lower)

$\underline{\underline{A}}$ = matrix of coefficients derived from Eqs. (4), (5) and (6)

$\underline{p}(t)$ = vector of boundary condition functions

If $d\underline{C}/dt = 0$ (property in steady-state) and inputs occur in upper layer upstream boundary and lower layer downstream boundary, algebraic substitution shows that Eq. (7) is solved by $C_i = a\,S_i + b$, a and b determined by the boundary condition C, S pairs.

This model improves on Pritchard (1969) by letting concentration variables define box boundary concentrations with mean box values calculated by Eq. (4), whereas the opposite approach is used in the previous model. This optimizes the use of observed salinity data by using it directly in Eq. (2) which is sensitive to small changes in salinity.

This paper discusses the relations between freshwater flow, currents and salinity in the lower Hudson Estuary relevant to the construction of a box model, and applies the model to the distribution of chlorophyll *a* , an index of phytoplankton biomass. The Chlorophyll *a* field derived from the model can be compared to observed Chlorophyll *a* field to determine whether additional source (growth, resuspension) or sink (grazing, sinking) terms are needed to balance Eq. (7). These terms can be calculated by direct substitution of observed C's into Eq. (7). Thus the model provides a method for separating the component of the phytoplankton dynamics due to circulation from other effects and the estimation of flushing times of phytoplankton from the estuary. The characteristics of the data set used are discussed in Malone et al. (1980) and the present work extends and refines the flux calculations given therein.

MATERIALS AND METHODS

Samples were collected at approximately weekly intervals from February to June and July to September during 1977 and 1978. Surface chlorophyll (*in vivo* fluorescence) and salinity (conductivity and temperature) were monitored continuously with and against the tide along a transect between MP -7 and MP -25 (Figure 1). Vertical profiles of current speed and direction, temperature, salinity and chlorophyll *a* were obtained at 6 stations (Figure 1) with a Savonius rotor current meter, conductivity-temperature-depth sensor, submersible pump and bottle casts. Vertical profiles were obtained every 1 to 3 h over two tidal cycles on 8 occasions at MP -7 and 2 occasions at MP 18. Bottles were used to collect samples for extracted chlorophyll *a* and primary productivity

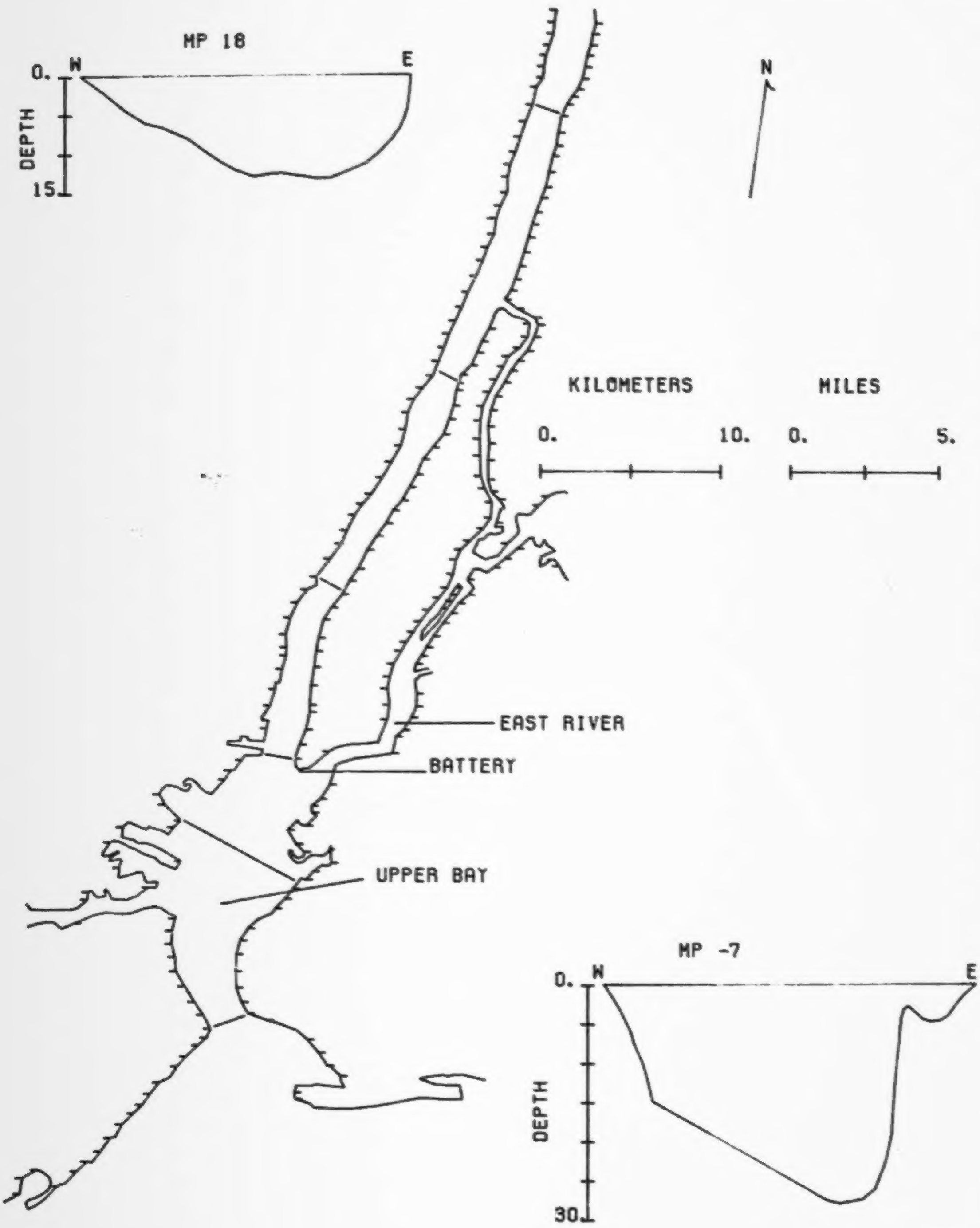

MP 18
0.
W
E
DEPTH
15
N
KILOMETERS
0.
10.
MILES
0.
5.
EAST RIVER
BATTERY
UPPER BAY
MP -7
0.
W
E
DEPTH
30

Figure 1. The Lower Hudson Estuary with station locations and box boundaries indicated by lines normal to axis at MP -7, MP -3, MP 0, MP 6, MP 11, MP 18 (MP = mile point, miles north (+) or south (-) of the Battery). Insets show cross-sectional profiles at MP -7, and MP 18. The Upper Bay station location actually varied between MP -4 (1977) and MP -2 (1978).

experiments as described by Malone (1977). Netplankton and nannoplankton refer to phytoplankton populations that were retained and passed by a 20 µm mesh screen, respectively.

Freshwater flow of the Hudson River at Green Island (250 km north of Upper Bay) was provided by the Water Resources Division of the Geological Survey, U. S. Department of Interior. Total freshwater flow in the lower estuary was calculated by applying a correction for lower basin flow (Hammond 1975; Deck 1980). Cross-sectional areas for each station were obtained from fathometer profiles, and volumes north of MP 0 were calculated using linearly varying area. In the upper bay the dimensional data of Quirk, Lawler, and Matusky (1970) was employed.

RESULTS AND DISCUSSION

FRESHWATER FLOW

During 1977 and 1978, freshwater flow at Green Island (Q_{GI}) ranged from 37 x 10^7 m^3 d^{-1} (spring) to below 2 x 10^7 $m^3 d^{-1}$ (summer). The 25-year annual mean is 3.1 x 10^7 m^3 d^{-1}. In the spring there were large amplitude peaks of short duration which arrived earlier and were higher in 1977 than in 1978 (Figure 2). Summer flow was much lower and less variable (1977 $\bar{x}$ = 1.23, sd = 0.31, 1978 $\bar{x}$ = 1.32 sd = 0.37). Green Island is located at mile point (MP) 154, 136 miles upstream from the northern most station. Consequently, two corrections must be applied to Q_{GI} to estimate freshwater flow into the lower estuary (Q_f): (1) lower basin inputs must be added to Q_{GI} and (2) a lag must be used to account for the time required for a change in Q_{GI} to be reflected in Q_f. Hammond (1975) and Deck (1980) adjusted Q_{GI} for lower basin contributions to freshwater flow in the estuary (Q_f), but possible lag times and spreading of flow peaks were not accounted for. Lag time estimates range from 5 to 20 days (Stewart 1958; Hammond 1975), though the possibility of shorter times in the spring has been noted (Hammond 1975). Since adjusted Q_{GI} can change as much as 25 x 10^7 m3 d^{-1} in as little as 4 d during spring (Figure 2), this is the season when accurate lags are most needed.

Lag times between Q_{GI} and Q_f were examined through the correlation of $\langle S \rangle_x$, the average surface salinity between MP 25 and MP -7. Q_{GI} was adjusted as above and smoothed by a centered moving average to allow for flow peak spreading during transit. The averaging period was varied as a function of the lag (Table 1).

During high flow ($Q_f \geq 5$ x 10^7 m^3 d^{-1}) variations in $\langle S \rangle x$ were mainly a function of QHf changes. By comparing variations in Q_{GI} with variations in $\langle S \rangle_x$ a lag of 1 day was found to give the maximum correlation (Figure 2). The correlation was also examined by fitting $\langle S_x \rangle = (\langle S \rangle_x)_o \exp(b\ Q_f)$ (cf. Eq. 1a) for lag times of 11, 7, and 1 days. A one-day lag time gave the best fit for both high and low (Q_f 5 x 10^7 m^3 d^{-1}) flow conditions (Table 1). Such a short lag under low flow conditions indicates the poor sensitivity of the model during low flow since this lag is shorter than the minimum low flow lag of 5 d calcu-

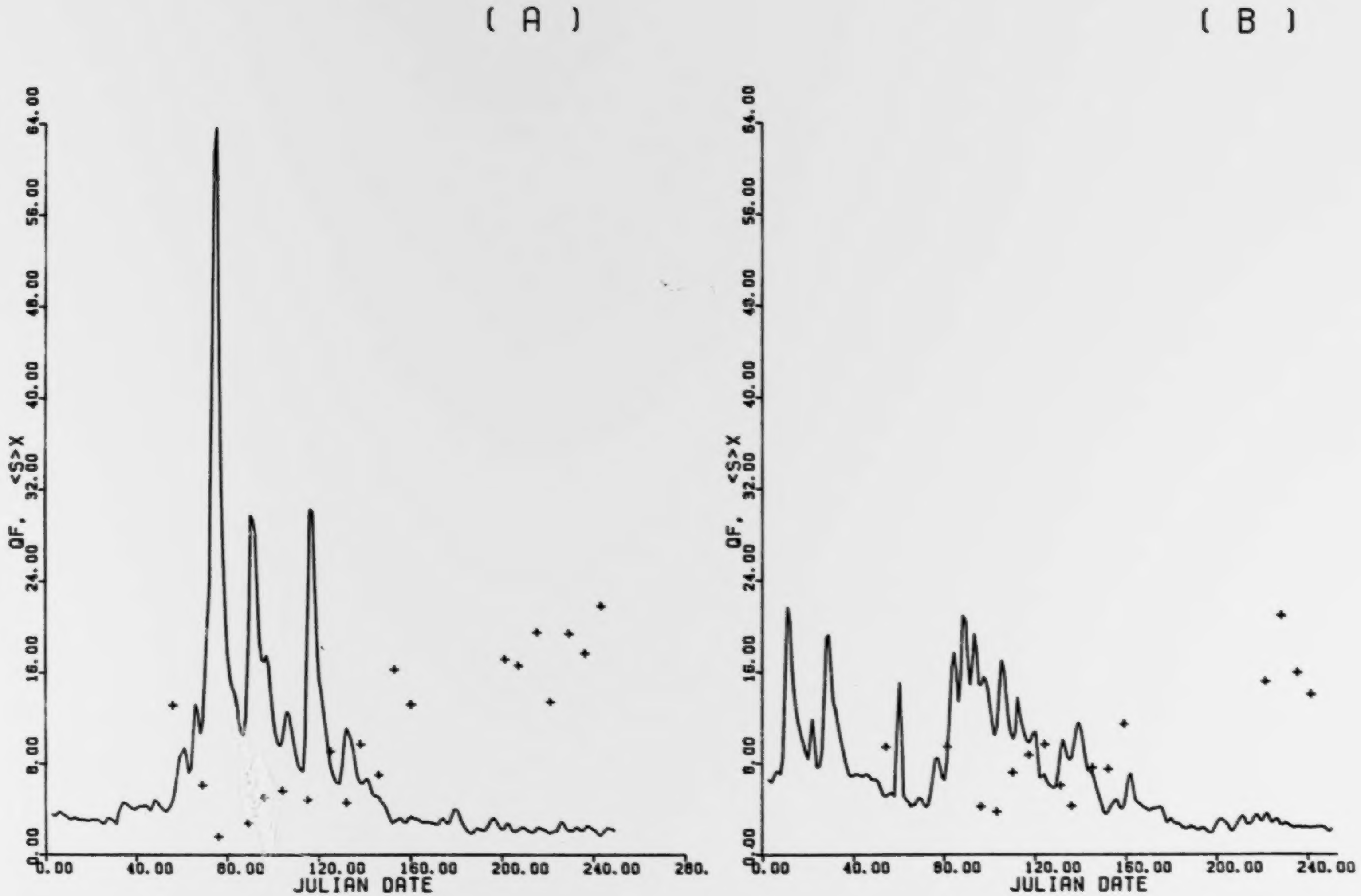


Figure 2. Fresh water flow of the Hudson River at Green Island (10^7 m^3 d^{-1}) smoothed and lagged 1 day (—) and mean surface salinity (+) in parts per thousand in the lower Hudson Estuary for 1977 (A) and 1978 (B); $Q_f = 10^7\ m^3\ d^{-1}$, $<s>_x$ = o/oo.

Table 1. Statistics for regession of mean surface salinity ($\langle S \rangle_x$) on adjusted and smoothed Q_{GI} using equation $\langle S \rangle_x = (\langle S \rangle_x)_o \exp (b\ Q_f)$ for high flow ($Q_f \geq 5 \times 10^7\ m^3\ d^{-1}$) and low flow ($Q_f \geq 5 \times 10^7\ m^3\ d^{-1}$). For the 1 day lag Q_{GI} was smoothed with a three day average with weights ¼,½,¼. For the 7 and 11 day lag Q_{GI} was smoothed over a period equal to the lag.

	High Flow				Low Flow			
Lag time (d)	$(\langle S \rangle_x)_o$	b	r^2	F	$(\langle S \rangle_x)_o$	b	r^2	F
1	10.62	-.045	.64	33.8**	23.71	-.139	.34	6.2*
7	9.55	0.041	.17	3.98ns	21.61	-.097	.21	3.2ns
11		not done			23.47	-.132	.20	3.0ns

ns - regression not significant

* - $p < 0.05$

** - $P < .01$

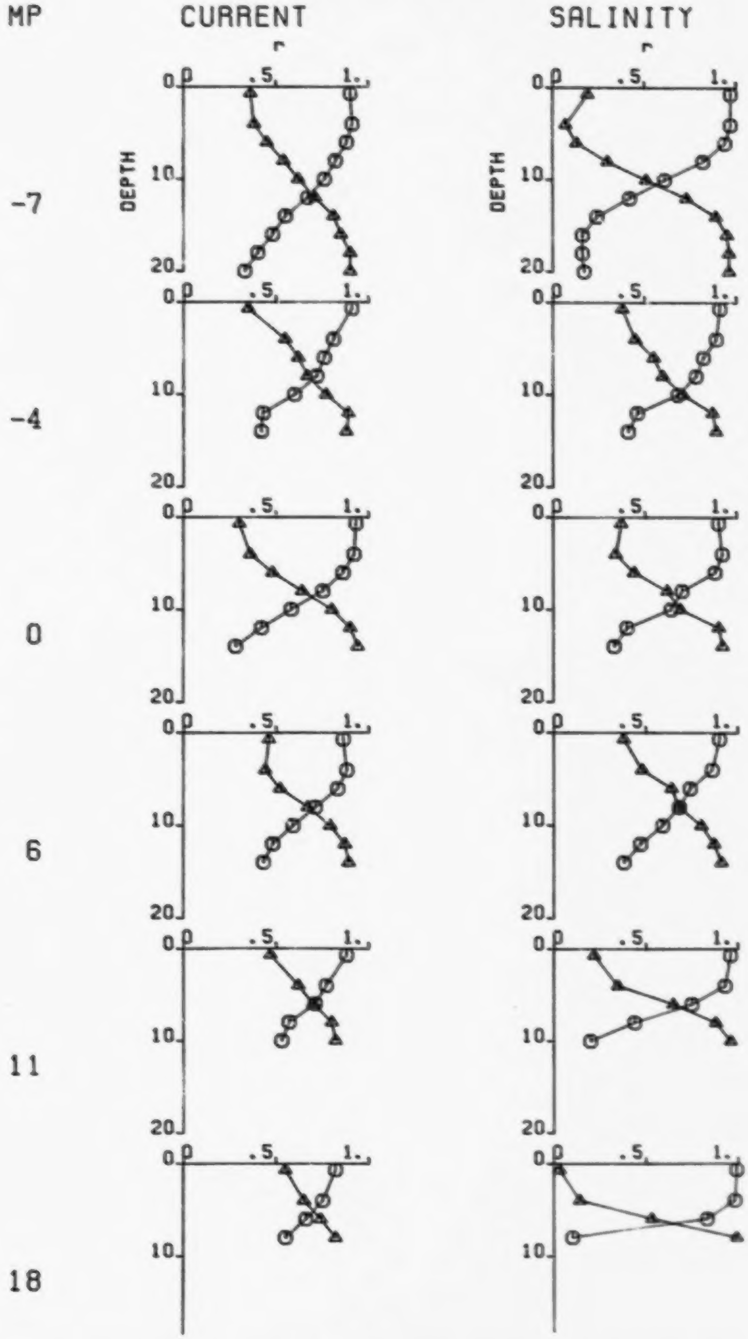


Figure 3. The correlation (r) of original variables and the first two principal components from vertical profiles of current velocity and salinity at stations in the lower estuary in 1977. Velocities or salinities that correlate with a common component tend to co-vary. On this basis components were labelled "surface" (o) or "bottom" (Δ). Similar results were obtained from analysis of 1978 salinity data.

lated from the volume of water needed to create a Green Island to Battery gradient (Hammond 1975). However, since variations in Q_{GI} during this time are small, the lag-related errors in Q_f estimates are also small and 1 day lag time was used under all flow conditions.

SALINITY PROFILES

Tidally averaged salinity in the upper and lower layers are needed to compute volume transports between layers and boxes. Since the required data are not available except occasionally at MP -7 and MP 18, an empirical model of tidal variations in salinity was used to estimate tidal averages given a salinity profile and the vertical boundary between surface and bottom layers at each station. The vertical boundary was determined by examining the principal components (Morrison 1976) of velocity and salinity profiles averaged over 2-m sections at each station (Figure 3). Two components accounted for most of the variance (94%-98%) in both velocity and salinity. Varimax rotation (Morrison 1976) of the two-component structure at each station showed a "surface" and "bottom" component with a mid-water column boundary (Figure 3). The velocity and salinity structure at each station was similar, in agreement with the Hudson's classification as a partially mixed estuary with dominantly two layer flow. Using this analysis as a guide, upper and lower layer mean salinities were determined from depths having a larger correlation with component 1 or component 2, respectively.

These upper and lower layer salinities were then used to estimate tidally averaged salinities by using them to fit an empirical model for salinity distribution in each layer.

$$S\,(x,t) = So\,\exp\,(-kx) + St\,(-\cos\,(2\,\pi t)) \qquad (9)$$

x = distance upstream from MP -7
t = proportion of time elapsed in tidal cycle (LWS-LWS) at x (determined from USCG tide tables)
S_t = half tidal range, S_o = mean salinity at MP -7
k = fitted advection-diffusion parameter

An estimate of tidally averaged salinity was then obtained by integrating (9) over the tidal cycle at each station. Since the equation is non-linear, Gauss-Newton non-linear regression was used to determine the least squares set of parameters (Snedecor and Cochran 1978) for each set of two successive sampling times (1 day apart 1977, 1 week apart 1978). Data were not pooled if Q_f changed significantly during the sample period, and data sets with less than 2 degrees of freedom were omitted.

This empirical model accounted for observed distributions fairly well, implying a relatively small contribution to S (x,t) by higher order terms such as distance dependent S_t and other periodic tidal components. The fitted equations had high coefficients of determination (1977 20 out of 22 had $r^2 \geq 0.88$, 1978 17 out of 20 had $r^2 > 0.83$) and estimated half-tidal ranges were close to ranges observed at MP -7 and MP 18 when profiles were obtained at 1-3 h intervals. Variations in k reflected the decrease in longitudinal salinity gradient from spring to summer and stronger gradients in the upper than the lower layer. Using the same method on whole water column averages, an average lower estuary cross-section area of 1.8×10^4 m^2, and Q_f as calculated above, values of E (= $-Q_f/kA$) from 500 to 5000 m^2/s were calculated over a Q_f range of 2 - 20 x 10 m^3 d^{-1}. Simpson and Hammond (submitted) have suggested 500 to 2500 m^2/s for lower estuary over a Q_f range of 2 - 10 x 10^7 m^3 d^{-1}.

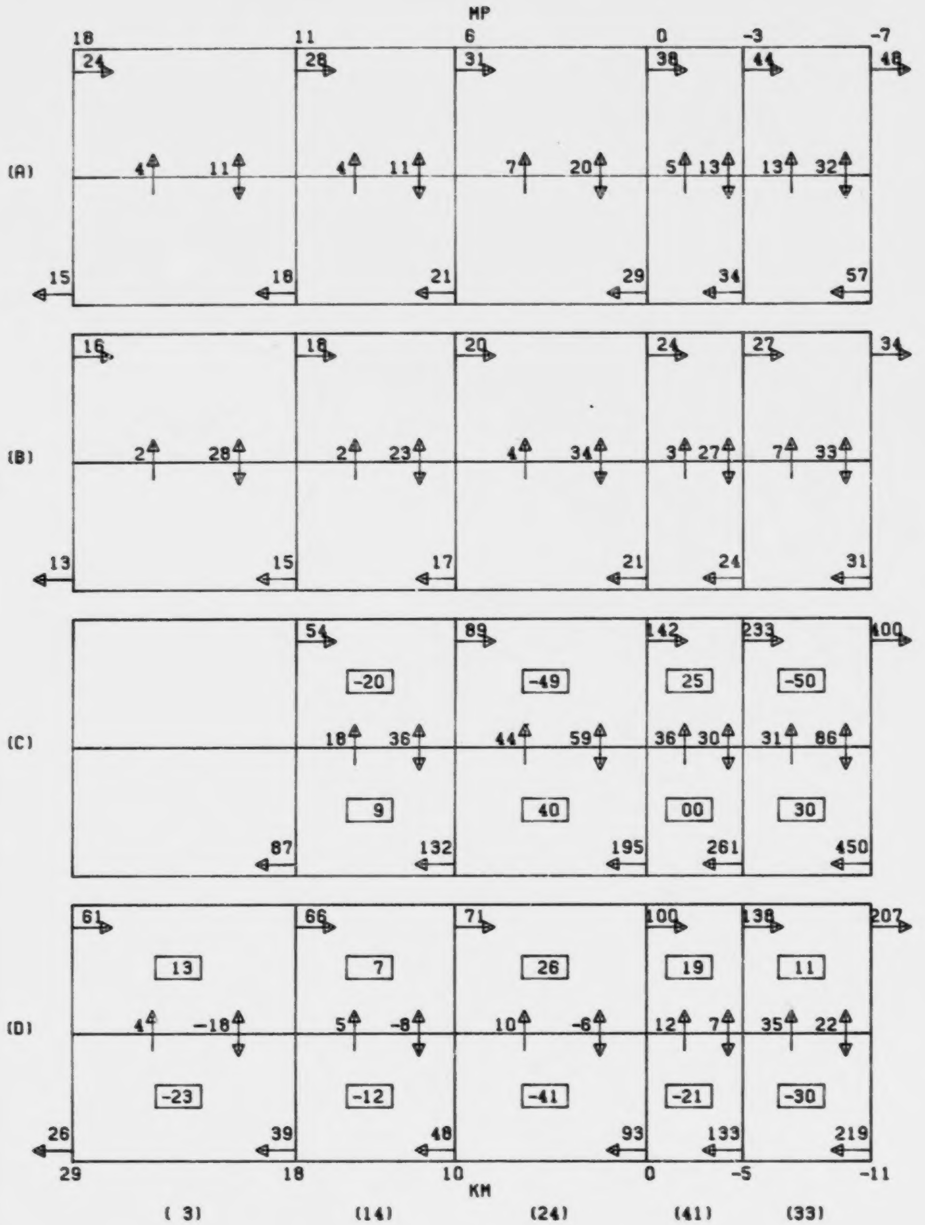
VOLUME TRANSPORTS

Mean transports under high and low flow conditions were higher than mean Q_f in each layer (Figure 4). The ratio of Q_u to Q_f ranged from 2 to 6 under high flow conditions and from 5 to 12 under the low flow conditions. Ratios of 10 to 40 have been reported in other partially stratified estuaries, e.g. the James River (Pritchard 1967), Mersey Estuary (Bowden 1960), and Juan de Fuca Straight (Tully 1958). Differences in this ratio between high and low flow periods were primarily due to changes in Q_f with Q_u (and Q_l) remaining relatively constant. Such stability over a wide range of Q_f reflects the inverse relationship between Q_f and vertical salinity gradients and is primarily a consequence of an increase in vertical exchange under low flow conditions (Figure 4).

CHLOROPHYLL *a* DISTRIBUTIONS

Mean upper and lower layer Chlorophyll *a* concentrations for the box model were computed from vertical profiles of Chlorophyll *a* by averaging over the depth ranges used to average salinity. When profiles were available from two consecutive days at a given station they were averaged. Tidal variations in Chlorophyll *a* were considerable but, unlike salinity, tidally averaged profiles were not calculated. Mean Chlorophyll *a* over two tidal cycles at stations MP -7 and MP 18 had average coefficients of variation of 44 percent (27 to 60%) in the upper and 31 percent (16 to 57%) in the lower layer. However, the upper and lower layer Chlorophyll *a* concentrations were positively correlated (r 0.60 to 0.99, $P < 0.05$) except in May 1977, 1978 when r was not significant. This implies that the between layer differences used to calculate source and sink terms were less variable than Chlorophyll *a* concentrations used to calculate upper and lower layer fluxes.

Flushing times were calculated by applying Chlorophyll *a* distribution data to Eq. (7) and setting the boundary inputs to zero. Solutions for time varying Chlorophyll *a* obtained through the method of similarity transformations (Noble and Daniel 1977) had the general form of p_k exp (λk^t) + p_o, where λ_k is the k^{th} eigenvalue of $\underline{\underline{A}}$ (Eq. 7) and the p's


MP
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0
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(A)
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28
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44
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4
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(B)
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28
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(C)
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93
133
219
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0
-5
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KM
(3)
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(24)
(41)
(33)

Figure 4. Two dimensional box model for the lower Hudson Estuary for stations between MP 18 and MP -7. Models (A) and (B) are for volume transport (10^7 m^3 d^{-1}) during high flow and low flow periods respectively. Models (E) and (D) are for mass transport (10^7 mg Chl a d^{-1}), during high and low periods respectively. Arrows indicate downstream upper layer flow, upstream lower layer flow, and vertical advection from lower to upper layer. Double headed arrows in (A) and (B) indicate the vertical exchange coefficient, E (10^7 kg d^{-1} ppt^{-1}). Double headed arrows in (C) and (D) indicate vertical transport of Chl a due to exchange ([+] upward [-] downward), and source (+) and sink (-) fluxes are in the center boxes.

are constants. Flushing times determined from the full solution (t_n, time to 90% of difference between initial and asymptotic total amount of Chlorophyll *a* in the estuary) were found to be close to $-\ln(0.1)/\lambda_n$ which is the 90 percent decay time for λ_n, the smallest magnitude eigenvalue of $\underline{A}$ Solutions for specific boundary conditions were about ½ day less than t_n and in only 2 out of 25 cases did the difference slightly exceed one day. Using this simplification, response times averaged 2.8 d during high flow and 5.3 d during low flow. The minimum (0.8 d) occurred during 1977 peak flow and the maximum (6.8 d) during 1977 low flow. Because of the relative stability of estuarine net circulation with respect Q_f variations (Figure 4), flushing times remain short even during low flow periods (c.f. Ketchum 1967). A well-mixed lower Hudson Estuary (i.e. $Q_f \lll$ tidal flows) would not be as stable. Mean water residence times (=Estuary volume/Q_f) would be longer, increasing from 7.6 d (high flow) to 26.0 d (low flow).

CHLOROPHYLL *a* FLUXES

In light of the possible effects of variability of Chlorophyll *a* on scales of a tidal cycle (discussed above) to several days (discussed below), we chose to examine the mean Chlorophyll *a* fluxes during high and low flow periods (roughly winter to early-spring and late spring to summer). Though this does not resolve short term variations, such as the occurrence and fate of particular phytoplankton blooms, a fairly reliable picture emerges of Chlorophyll *a* fluxes in terms of the seasonal variation of flow regime and biomass of phytoplankton size fractions (Malone 1977, Malone et al. 1980).

Input fluxes to the estuary reflected the occurrence of net-plankton blooms in adjacent coastal waters and advection into the estuary under high flow and growth of nannoplankton within the estuary under low flow conditions (Malone 1977, Malone et al. 1980). During high flow the main source of Chlorophyll *a* was at the mouth of the estuary (MP-7) in the lower layer (Figure 4), where bottle samples had a mean of 64 percent Chllorophyll *a* in the net-plankton fraction (range 49-90%). The most important input during low flow was the upstream boundary upper layer where nannoplankton accounted for 92 percent of Chlorophyll *a* on the average (range 82-97%). A smaller input of Chlorophyll *a* occurred at MP -7 (12×10^7 mg Chl *a* d^{-1} vs. 35×10^7 mg Chl *a* d^{-1} at MP 18), and, unlike the high flow period, was not dominated by net-plankton (mean % net 31%, range 2% to 84%).

Fluxes within the estuary showed that Chlorophyll *a* propagated longitudinally and vertically away from its sources (Figure 4). Chlorophyll *a* was advected upstream during high flow by a consistently larger lower layer influx than downstream upper layer flux. Vertical advection and exchange transported Chlorophyll *a* from the lower to upper layers. Thus the flux of Chlorophyll *a* during high flow followed the longitudinal and vertical flux into the lower layer, a consequence of vertical exchange fluxes from sources in the upper layer. South of MP 0 net vertical fluxes into the upper layer reflected the lower layer input at MP -7.

The high flow pattern of large sinks in the upper layer and smaller source fluxes in the lower layer (except between MP 0 and MP -3) is best explained by the sinking of phytoplankton within the estuary. An average sinking rate of 3.5 m d^{-1}

would account for the Chlorophyll *a* fluxes from the upper layer (Table 2). This is a reasonable sinking rate for netplankton diatoms (Smayda 1970), and comparable to estimates of 2 to 4 m d^{-1} in the apex of the New York Bight (Malone and Chervin 1979). Resuspension of phytoplankton from estuarine sediments may contribute locally to source fluxes in the lower layer, but since there is no net source flux from the estuary any such contribution must be balanced by settling out elsewhere in the lower layer.

The source flux in the upper layer of the upper bay segment (MP 0 to MP -3) was unusual as the only high flow upper layer source flux and may have been an input from the adjacent East River (Figure 1), which is not included in the model. Since significant growth did not occur elsewhere in the estuary upper layer and there is no evidence that growth rate varied within the estuary, it is unlikely that the source flux was due to phytoplankton growth. Furthermore, if the source flux was due to growth, the model fluxes imply that the average doubling times would have been 0.4 d (Table 2). This is shorter than the phytoplankton doubling times (1-2 d) reported for the lower estuary during spring (Malone 1977). Since direct measurements of exchange with the East River (Figure 1) have not been made, this question and the related question of why the source flux anomaly was absent during low flow conditions (i.e. upper bay fluxes were similar to fluxes in adjacent boxes) cannot be resolved. Clearly the details of Chlorophyll *a* circulation in the upper bay merit closer study.

The pattern of source and sink fluxes during low flow was consistent with high phytoplankton growth rates during the summer, in the upper layer and high grazing rates by zooplankton in both layers. The average growth rate estimated from source and sink fluxes was 1.22 d^{-1} (Table 2). This is high but comparable to a growth rate of 1.27 d^{-1} estimated from ^{14}C primary productivity (Malone 1977). Estimates of potential fluxes due to copepod grazing were computed from July per copepod grazing rates in the New York Bight apex (Chervin et al. in press) and copepod abundances in the estuary. These estimates were in rough agreement with lower layer sink fluxes (Figure 4). The above calculations assume that copepod abundances and grazing rates are the same in the upper and lower layers. Any vertical variations would strongly affect rate estimates, and this recommends the separate sampling of each layer in future studies of estuary zooplankton.

NON-STEADY-STATE VARIATIONS IN CHLOROPHYLL *a*

The above discussion assumes that source and sink fluxes were in "local" steady state, i.e. that the rate of significant variation in the boundary conditions and processes contributing to within box fluxes is slower than the response rate of the lower estuary. Generally, the response times were shorter than the weekly sampling interval and it is not known how much variation occurred on time scales shorter than 7 days. However, the time scales of phytoplankton blooms are generally longer than the estuary response times given here. Netplankton blooms in offshore waters during winter-spring typically last 1 to 2 weeks (Malone and Chervin 1979, Malone et al. in press). Nanoplankton biomass at the upstream upper layer was fairly constant during most of the low flow period (mean

Table 2. Rates computed from model source and sink fluxes for high flow and low flow conditions.

Box		Mean Chl a		Specific rates: upper layer			
MP	to MP	Upper layer	Lower layer	Gain[a]	Loss[b,c]	Growth[d]	Doubling Time[e]
				High Flow			
-7.0	-3.0	6.86	9.02				
-3.0	0.0	5.01	7.82	0.80	0.90	1.70	0.4
0.0	6.0	3.60	6.96				
6.0	11.0	2.73	5.86				
Entire upper layer mean sinking rate[f]					0.69 (3.5 m d^{-1})		
				Low Flow			
-7.0	-3.0	6.02	6.90	0.20	0.44	0.64	1.0
-3.0	0.0	4.76	5.15	0.51	0.46	0.99	0.7
0.0	6.0	4.06	3.62	1.22	1.32	2.54	0.3
6.0	11.0	4.09	2.61	0.41	0.96	1.37	0.5
11.0	18.0	4.03	1.97	0.50	1.72	2.22	0.3
Entire upper layer				0.50	0.72	1.22	0.6

[a] Gain = source flux/total amount of Chl *a* in the box (i.e. Chl *a* concentration x box volume).

[b] Loss = sink flux/total amount of Chl *a* in the adjacent MP -3 to Mp -7 box. It was assumed that the loss rate in the MP 0 MP 3 upper layer was the same.

[c] Loss = sink flux /total amount of Chl *a* in the corresponding lower layer box assumed to also apply to the upper layer.

[d] Growth rate = gain + loss.

[e] Doubling time = ln 2/growth rate.

[f] Sinking rate needed to account for a loss rate of 0.69 d^{-1} over the mean depth difference between upper and lower layer of 5.1 m.

4.43 µg 1^{-1}, 1 sd 1.35 µg 1^{-1}) when growth rates are high and fairly constant (Malone 1977).

A few exceptions to this overall pattern may have occurred, but their effect on means calculated over high and low flow periods should be small. Not included in above nannoplankton biomass mean are two occasions when Chlorophyll a exceeded 10 µg 1^{-1}. At these times the day to day variability of Chlorophyll a was high (i.e. > factor of 2) probably as a result of downstream advection of a "patch" of Chlorophyll a from the upper estuary (Malone et al. 1980). During low flow variations also occurred at the lower layer boundary at MP-7 (mean Chlorophyll a 8.06 µg 1^{-1}, sd 6.24 µg 1^{-1}). These variations were probably related to inputs from Raritan Bay (O'Reilly et al. 1976), but it is not known how these inputs change with time.

CONCLUSIONS AND RECOMMENDATIONS

MODELING APPROACH

The two-dimensional box model based on suitably averaged and corrected salinity data is a valuable tool for studying phytoplankton distributions in estuaries. In addition to describing the essential features of two-layered estuarine circulation and interactions between estuarine and coastal waters, the model provides independent estimates of fluxes due to estuarine circulation and fluxes due to other processes. Flux component estimates for the lower Hudson Estuary compared reasonably with the results of other analysis. The seasonal variation in Chlorophyll a circulation was consistent with previous observations on the direction of Chlorophyll a transports into and within the estuary (Malone 1977, Malone et al. 1980). More importantly, rates of phytoplankton growth, sinking, and grazing inferred from source and sink fluxes agreed with rates calculated from experimental data. Hopefully the present success of the two-dimensional box model will motivate its application to other, similar situations.

FRESHWATER FLOW EFFECTS

Using the two-dimensional box model we can see the results of natural variations in freshwater flow on circulation and response times in the lower estuary. The estuarine transport and increases in response time are small compared to changes in Q_f. This result probably applies to other partially mixed estuaries of fairly constant cross-sectional area, such as the James River (Pritchard 1967). However, modifications to the model to study the effect of very low Q_fs will not be valid in general, since the Q_f at which the estuary would no longer be partially mixed and the two-dimensional box model would not apply cannot be determined by such an empirical approach. Independent estimates of salt transport at MP -7 showed a similar stabilizing tendency, in which estuarine circulation is maintained by increasing influx of salt as freshwater flow increased (Hunkins submitted).

In light of this stability the direct effect of changes in freshwater flow on phytoplankton biomass in the lower estuary was small compared to the effects of seasonal variations in rates of phytoplankton growth and grazing within the estuary and the development of netplankton blooms in adjacent coastal water (Malone 1977, Malone et al. 1980, Malone and Chervin 1979).

During both flow regimes the

estuary was a net sink for Chlorophyll a though the reasons for this were different in each case. During high flow when advection from adjacent coastal water was the main source of Chlorophyll a, only a small percentage of the input was lost in the lower estuary (4%) (probably as a result of sinking). The rest was recycled back into coastal waters (89%) or further upstream (7%). The lower estuary was a sink with respect to both the upper estuary and offshore waters during low flow. The loss was 17 percent of total input. However, the loss was the net result of the active processes of growth (mean for lower estuary low flow by above calculations 192×10^7 mg Chl a d^{-1}) and grazing (mean 239×10^7 mg Chl a d^{-1}). Thus phytoplankton dynamics changed from a passive system of advection and sinking during high flow to an active system of growth and grazing during low flow.

ACKNOWLEDGEMENTS

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LITERATURE CITED

Abood, K.A. Circulation in the Hudson Estuary. Roels, O.A. ed. Hudson River colloquim. Annals of the New York Academy of Sciences 250:39-111; 1974.

Bowden, K.F. Circulation and mixing in the Mersey Estuary. International Association of Scientific Hydrology. Committee of Surface Waters Publication 51: 352-360; 1960.

Chervin, M.B.; Garside, C.; Litchfield, C.D.; Malone, T.C.; Thomas, J.P. Synoptic investigation of nutrient cycling in the plume of the Hudson and Raritan Rivers. Malone, T.C. ed. NOAA Tech. Report. (in press).

Deck, B. Nutrient element distributions in the Hudson estuary. New York: Columbia University; 1980. Dissertation.

Hammond, D.E. Dissolved gases and kinetic processes in the Hudson River Estuary. New York: Columbia University; 1975. 161 p. Thesis.

Hansen, D. V. Salt balance and circulation in partially mixed estuaries. Lauff, G.H. ed. Estuaries. Washington, D.C.: American Association for the Advancement of Science; 1967: 45-51.

Hunkins, K. Salt transport in the Hudson Estuary. Submitted to J. Phys. Oceanogr.; 1980.

Ketchum, B.H. Hydrographic factors involved in dispersion of pollutants introduced into tidal streams. J. Boston Soc. Civil Engrs. 37:296-314; 1967.

Malone, T. C. Environmental regulation of phytoplankton productivity in the lower Hudson Estuary. Estuarine Coastal Mar. Sci. 5: 157-171; 1977.

Malone, T. C.; Chervin, M. The production and fate of phytoplankton size fractions in the plume of the Hudson River, New York Bight. Limnol. Oceanogr. 24:683-696; 1979.

Malone, T.C.; Neale, P.J.; Boardman

D.C. Influences of estuarine circulation on the distribution and biomass of phytoplankton size fractions. Kennedy, V.S. ed. Estuarine perspectives. New York: Academic Press; 1980.

Malone, T.C.; Garside, C.; Neale, P.J. Effects of silicate depletion on photosynthesis by diatoms in the plume of the Hudson River. Mar. Biol. 58: 197-204; 1980.

Morrison, D.F. Multivariate statistical methods. New York, NY: McGraw-Hill Book Co. 1976: 266-301.

Noble, B.; Daniel, J.W. Applied linear algebra. Englewood Cliffs, N.J.: Prentice-Hall, Inc.; 1977: 393-402.

O'Reilly, J. E.; Thomas, J.P.; Evans, C.E. Annual primary production (nannoplankton, netplankton, dissolved organic matter) in the Lower New York Bay. (U.S. Dept. of Commerce NOAA) Paper #19 McKeon, W.H. and Lauer, G. J. ed. Fourth Symposium on Hudson River Ecology. Hudson River Environmental Society, Inc., N.Y. 1976.

Pritchard, D. W. Observations of circulation in coastal plain estuaries. Lauff, G.H. ed. Estuaries. Washington, D.C.: American Association for the Advancement of Science; 1967: 37-44.

Pritchard, D.W. Dispersion and flushing of pollutants in estuaries. J. Hydraulics Division, Proc. Am. Soc. Proc. Am. Soc. Civil Engineers 95: 115-124; 1969.

Quirk, Lawler, and Matusky Engineers. Assimilative capacity study. Albany, NY: New York State Dept. of Environmental Conservation; 1970: 38-39.

Simpson, J.J.; Hammond, D.E. Application of one-dimensional models to the Hudson River Estuary. Unpublished.

Smayda, T.J. The suspension and sinking of phytoplankton in the sea. Barnes, H. ed. Oceanography and marine biology, Vol. 5. George Allen and Unwin; 1970: 353-414.

Snedecor, G.W.; Cochran, W.G. Statistical methods. Ames, Iowa: The Iowa State University Press. 1978: 465-470.

Stewart, H.B. Upstream bottom currents in New York Harbor. Sci. 127: 1113-1115; 1958.

Stommel, H. Computation of pollution in a vertically mixed estuary. Sewage Ind. Wastes 25:1065-1071; 1953.

Taft, J.L.; Elliot, A.J.; Taylor, W.R. Box model analysis of Chesapeake Bay ammonium and nitrate fluxes. Wiley, M.L. ed. Estuarine interactions. New York: Academic Press; 1978: 115-130.

Tully, J.P. On structure, entrainment and transport in estuarine embayments. J. Mar. Res. 17: 523-535; 1958.

ASSESSMENT METHODOLOGIES FOR FRESHWATER INFLOWS TO CHESAPEAKE BAY

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ABSTRACT

The U.S. Environmental Protection Agency (EPA) Chesapeake Bay program is conducting an in-depth study to assess the principal factors having adverse impacts on the water quality of the bay. The program focuses on the point and nonpoint sources of pollution including nutrients and toxic chemicals that are associated with various land use practices. Water quality data will be evaluated through use of stochastic and deterministic models.

Field data collected on specific land uses from five test basins will be the basis for research to verify nonpoint source runoff rates. The field data will be used to calibrate and verify mathematical models in the test basins including nonpoint source loading, stream transport and estuarine processes. In particular, the estuarine models will simulate the impacts of nutrients on water quality. Fall line water quality data will serve as an independent data set to compare the point and nonpoint source projections associated with various land use activities.

Mathematical models will be employed on a bay-wide scale to generate nonpoint source loadings basinwide and to assess the impact from those loading on the tidal bay for the present (1980) and future (2000) conditions. Several growth scenarios that include consumptive freshwater use will be evaluated for their impact on water quality in the bay.

INTRODUCTION

The Chesapeake Bay is one of the largest estuarine complexes in North America. It is a moderately stratified system exhibiting temporally and spatially complex hydrodynamics in both the vertical and the horizontal directions (Pritchard 1967). The bay is 195 miles long with 8,000 miles of shoreline, a surface area of (tidal estuarine system) about 4,300 square miles and a drainage basin of 64,000 square miles. The bay receives drainage water from six states with the major supply contributed by the states of Pennsylvania, Maryland and Virginia (Figure 1). The Susquehanna River supplies about 50 percent of the annual freshwater supply with the Potomac and James Rivers accounting for another 35 percent.

Because of the bay's size, its wealth of natural and economic resources and the need for a continued stewardship, the U.S. Environmental Protection Agency was authorized in 1976 to initiate the Chesapeake Bay Program. The program is a five-year study of the environmental quality and resources management of the bay. From a list of 10 candidate problem areas, the program initially undertook work in three technical areas; (1) toxic chemicals in the food chain, (2) eutrophication (the supply

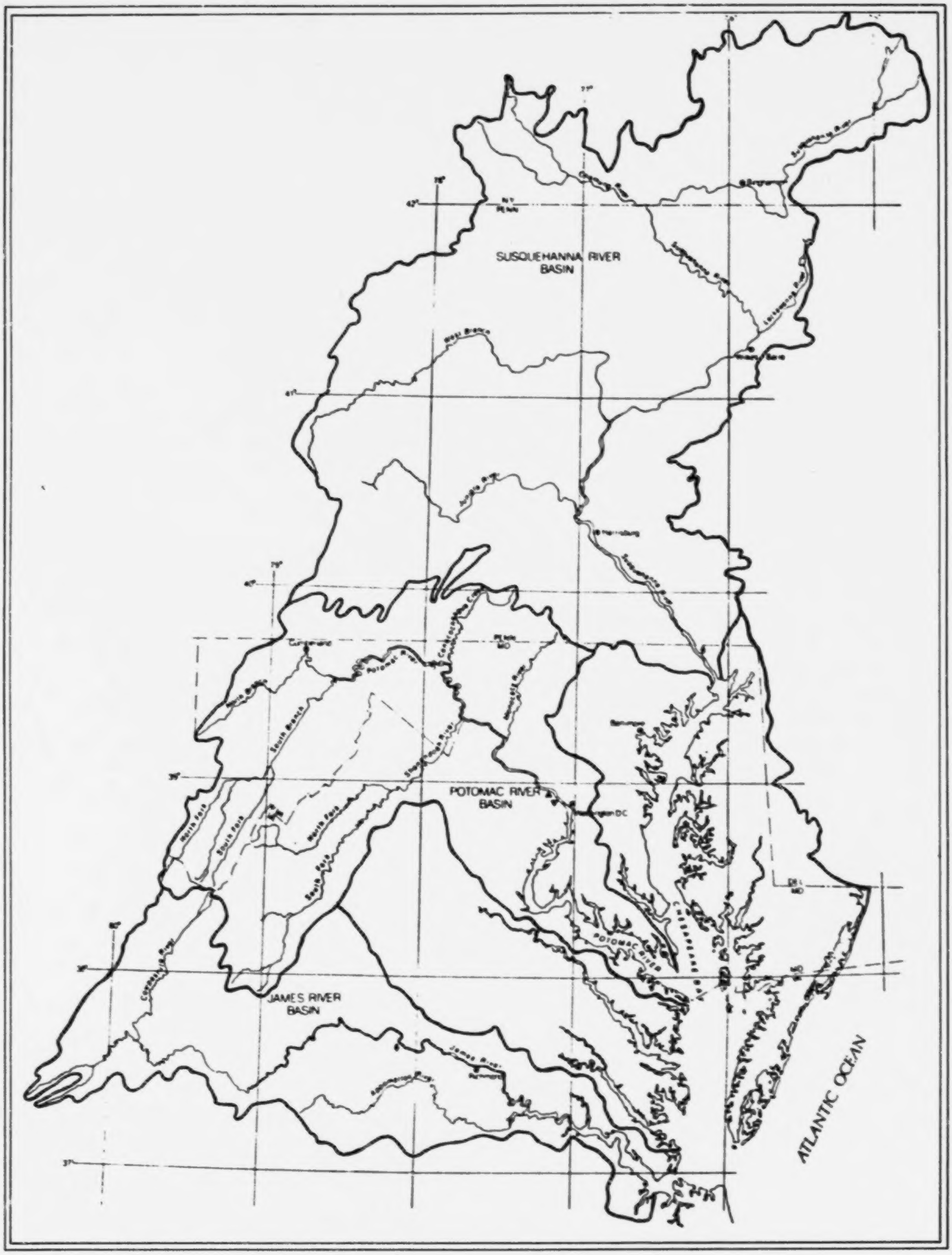
SUSQUEHANNA RIVER BASIN
POTOMAC RIVER BASIN
JAMES RIVER BASIN
ATLANTIC OCEAN

Figure 1. Chesapeake Bay and its drainage basin.

and accumulation of excess nutrients), and (3) the decline of submerged vegetation. Recently, dredging and spoil disposal were added as a fourth technical area. There is also a focus on management as a special area of study.

The program has a strong focus on water quality which is inextricably linked with freshwater supply. The many important uses of the bay including associated living resources require that water quality and quantity information be an integral part of the research plan (U.S. EPA 1980).

The quantity and timing of freshwater inflow to the bay is known to affect the circulation and distribution of salinity in the bay's waters. The salinity distribution has a fundamental relationship to the growth, reproduction and survival of the biota and to the chemistry of the bay's waters and sediments. Knowledge about circulation is important in specifying the distribution and characterization of pollutants and the resulting exposure of organisms to toxic chemicals and nutrients.

A conceptual program framework is provided to assist in the tracking of the numerous activities that range from an analysis of loadings of toxic chemicals and nutrients to the tidal estuarine system to possible management control alternatives (Figure 2). This paper emphasizes the modeling approach, model components, analytical approach and problem assessment. Beacuse of the state of the art and the allocation of resources, more emphasis is given to water quality modeling of nutrients and their relationship to the dissolved oxygen deficit than to toxic substances. All work discussed in this paper was undertaken with the intent of bay-wide application.

Work in the submerged aquatic vegetation area is oriented with emphasis on the distribution and abundance of the grasses environmental factors, e.g., light requirements and herbicide effects, ecological processes, e.g., nutrient cycling and value of the grasses as food and habitat to fish and wildlife. This work will not be discussed specifically in this paper except in the context of sources and transport and fate of nutrients, sediments and toxic chemicals within the bay system.

OBJECTIVES

NUTRIENTS

The objectives of the eutrophication program are: (1) To determine the state of the bay with regard to nutrient enrichment, past and present, (2) to quantify the nutrient levels in Chesapeake Bay based on water quality standards, non-degradation and water quality enhancement for years 1980 and 2000, and (3) to evaluate nutrient control alternatives for achieving and maintaining acceptable nutrient levels in the Chesapeake Bay at present (1980) and in the future (2000).

As referenced above, the second objective of the eutrophication program is to quantify nutrient loadings to the Chesapeake Bay from various sources. In order to achieve this important objective, current research is directed toward: (1) assessing point source information on municipal and industrial sources, (2) compiling statistics on land use and population trends in the bay basin, (3) measuring nutrient loadings from the major tributaries to the bay, (4) estimating nutrient fallout from the atmosphere, (5) verifying nonpoint source are some troubling discrepancies between the Texas commercial landings data reported by Chapman (1966) and those presented by Armstrong (1980).

The differences are not due to a 14 year lag in sampling years, because the data discussed by Armstrong (1980) were first presented by Copeland (1966) and may, in fact, be part of the same data set (1956-62) used by Chapman (1966). If the numbers reported by Chapman are too high, particularly the 450 kg/ha assigned to Galveston Bay, then his argument for a positive relationship between freshwater input and fisheries yield is not very compelling.

It seems clear that while there may be some estuaries in which there is a good correlation (either positive or negative) between freshwater discharge and fisheries yield, the mechanism involved is probably something other than a simple fertilizing effect of the river itself (eg. Huntsman 1955; Barrett and Ralph 1977; Sheridan and Livingston 1979). In fact, considering all of the factors that go into determining the catch of finfish and shellfish in an estuary, it is remarkable how similar the area-based yields are from most coastal marine systems.

SEASONAL CYCLES

There appear to be few systems in which the seasonal cycle in primary production corresponds with the cycle of river discharge (Figure 8). With the exception of Narragansett Bay and perhaps a few other areas which have a strong winter-spring phytoplankton bloom, the general pattern seems to be for production to peak during the summer, some months after river discharge has declined following spring runoff. Because the freshwater usually carries sediment with it, the offset in production may be due to decreasing turbidity as salinity rises or to a combination of increasing solar radiation and temperature (Figure 8). In the case of Narragansett Bay, the freshwater input is very small and initiation of the winter-spring bloom has been shown to be due to light and other factors rather than to river discharge (Hitchcock and Smayda 1977; Nixon et al. 1979).

It is possible to examine the potential contribution of freshwater nutrient inputs to the spring-summer phytoplankton bloom in a more general way. As river (or groundwater) flow increases, fresh water will accumulate in the estuary, and the salinity will decrease. As noted earlier, the annual salinity excursion for many estuaries appears to fall around 5 o/oo to 10 o/oo (Figure 5). A salinity decline of 5 o/oo will represent an accumulation of varying amounts of fresh water, depending on the salinity of the nearshore and estuarine water with which it is being mixed (Table 4). If the concentrations of dissolved inorganic nitrogen (the major limiting nutrient in coastal marine waters) in the river water lie between 10 to 100 µM, the amount of river-borne nitrogen per unit volume of lower salinity estuarine water can be calculated and an estimate made of the primary production this amount of nitrogen could support (Redfield 1934). The result suggests that in most estuaries the accumulation of "new" nitrogen from fresh water is not likely to support more than a few days of growth under bloom conditions when production rates often reach or exceed 500-1000 mg C/m^3/day. But the total primary production cannot be calculated without a knowledge of the turnover rate and residence time of the nitrogen in the estuary.

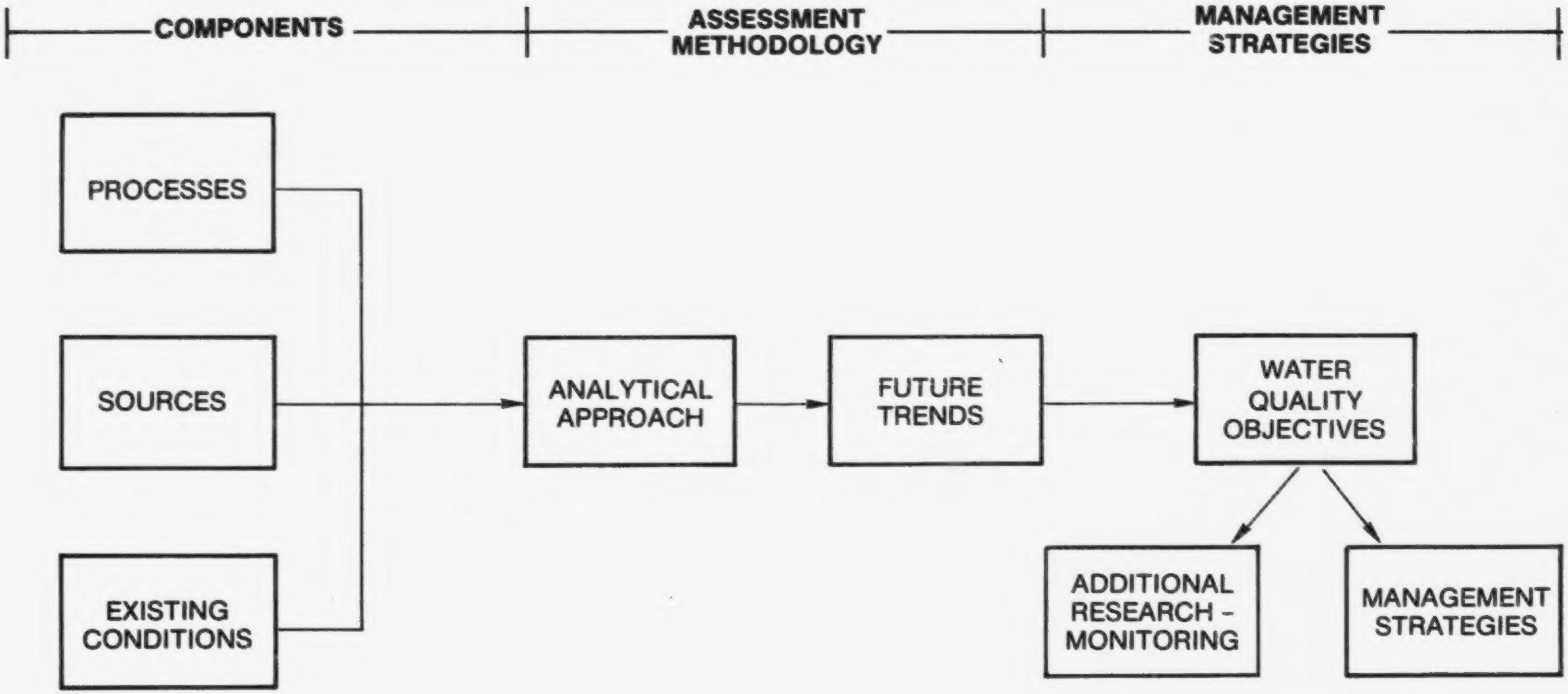
COMPONENTS
ASSESSMENT METHODOLOGY
MANAGEMENT STRATEGIES
PROCESSES
SOURCES
EXISTING CONDITIONS
ANALYTICAL APPROACH
FUTURE TRENDS
WATER QUALITY OBJECTIVES
ADDITIONAL RESEARCH - MONITORING
MANAGEMENT STRATEGIES

Figure 2. Conceptual framework for developing management strategies in Chesapeake Bay.

runoff from data collected on five test drainage basins in Pennsylvania, Maryland and Virginia, and (6) calibrating and verifying mathematical models to include nonpoint source loading models, stream transport models and estuarine response models.

TOXICS

The Chesapeake Bay Toxics Program has been designed to address a number of problems associated with the estuarine environment. Two of the greatest threats to an estuary are sediments and toxic materials. Sediments tend to fill in estuaries and toxic materials adversely impact the estuarine biota. These two factors are studied together since the majority of heavy metals, radionuclides and organic toxic chemicals, are known to adsorb to fine grain particles both in the water and sediments. To assess the impacts of these materials, the toxics program is pursuing research on the present distribution of sediments and toxic materials to the bay, and the behavior and fate of sediments and toxic materials within the bay. The first area of investigation will provide data about what toxic chemicals are in the system now, where they are located and their form (e.g., inorganic, organic, etc.). The second area of investigation will document the types of materials entering the bay, the various sources of these materials (natural and anthropogenic), and will provide a first estimate of the rates of addition to the estuary. The third area of investigation will delineate the routes and mechanisms of transport of sediments and toxic materials within the estuary, the sites of accumulation (sedimentation), the chemical behavior (mobilization and cycling) and will begin to identify biological impacts. Together, these studies will provide a baseline description of the estuarine system against which future changes can be measured. The overall goal of the toxics program is to provide a sound scientific foundation on which effective strategies can be built.

COMPONENTS OF METHODOLOGY

FALL LINE MONITORING

Through an interagency agreement with the EPA Chesapeake Bay Program, the U.S. Geological Survey is conducting a two-year intensive study at the fall line of the major rivers draining into the tidal Chesapeake Bay. The Susquehanna, Potomac and James monitoring sites are located at Conowingo, Maryland (dam and Rt. 40 bridge), Washington, D.C. (Chain Bridge), and at Cartersville, Virginia, respectively. Measurements are being made for suspended sediment, nitrogen, phosphorus, carbon, trace metals, pesticides, sulfate and major ions, chlorophyll a, total solids and freshwater discharge. Physical parameters are measured daily with nutrients and metals being monitored monthly (twice a month for Susquehanna). In addition, high-flow sampling over the hydrograph is being carried out to assess the impact from upland nonpoint source runoff. The products of this study include estimated input loadings to the bay of suspended sediment, major dissolved species, selected nutrient species, and trace metals, plus a seasonal characterization of pesticide runoff. Levels of confidence will be made by the United States Geological Survey (USGS) for the various loading curves. These field-measured loadings will be introduced into the bay-wide water quality model for calibration and verification purposes. Also, the USGS will compare its loading data with historical data to note any trends in loadings to the bay from the major tributaries. An interim data report of the USGS effort is now available (Lang and Grason 1980).

POINT SOURCE INVENTORY

The bay program will make estimates of municipal and industrial point source loadings from existing EPA and state agency files. Mason and McFadden (1980) reported that the EPA Waste Water Systems Inventory Survey is the best available data base for municipal point source discharges. This survey provides treatment plant flows for the present and projected design flows of municipal plants. Information is available for 1978 (actual) and year 2000 (projected) effluent concentrations of phosphorus, ammonia, total Kjeldahl nitrogen, and total nitrogen for all municipal point sources in the Chesapeake Bay basin with flows in excess of one million gallons per day. The most up-to-date and accurate information will be utilized during model calibration and verification and for all model production runs.

INTENSIVE WATERSHED STUDIES

A set of intensive watershed studies is being conducted to characterize runoff pollution loadings and to facilitate projections of nonpoint source loads in the Chesapeake Bay basin. The approach is to isolate small study sites which exhibit relatively homogeneous land use, geology, soils, topography, land surface maintenance practices, etc. These factors and others are being related to the nonpoint source loading regime observed during monitoring periods to characterize runoff water quality by quantifiable land and land use parameters. The technique of intensive monitoring of small watersheds was chosen because it represents the state of the art of runoff pollution assessment. The intensive watershed studies are intended to identify the specific sources of runoff pollution loads and also to identify some of the physical characteristics that determine the responses of each source to hydrometeorologic inputs. When the data are linked with appropriate water quality assessment tools, they will allow an assessment of the water quality impacts of present and future land use changes and provide the potential for the control of runoff loadings through the application of Best Management Practices (BMPs).

Presently, nonpoint monitoring programs have begun in the Occoquan River (9 sites) and Ware River (4 sites) watersheds in Virginia and the Pequea Creek basin (5 sites) in Pennsylvania. Similar studies are scheduled to begin this summer in Maryland watersheds (14 sites). Sites have been selected to represent a variety of land uses (18 Agricultural, 6 Forested, 6 Residential, 2 Mixed), soils, and geologic formations as well as various other parameters, e.g., slope. These sites are being monitored during both base flow and storm event conditions for a variety of pollutant constituents. In addition, the performances of several nonpoint pollution control measures are being evaluated. Measures of various land, land-surface and cultural parameters are being documented on each site for use in later characterization efforts to be made through the use of a deterministic computer-based hydrologic, water quality model.

ATMOSPHERIC INPUT

Atmospheric deposition of materials in the form of wet fall and dry fall has been identified as a significant source of metals and certain organic compounds to the Great Lakes. In order to determine the importance of atmospheric inputs to the Chesapeake Bay, a network of ten sampling stations fringing the bay has been established. At each station, both wet fall and dry fall will be continuously collected using Aerochem Metric model 301 samplers. Extensive chemical analysis will be performed on all of the samples for inorganic constituents, and on selected samples for organic compounds to provide an assessment of the types and amounts of materials contributed to the estuary from the atmosphere.

POINT SOURCE ASSESSMENT

Two approaches are being used to obtain data on toxic chemical loadings from point sources to the bay. The first approach utilizes information available from the National Pollution Discharge Elimination System permits. From these permits estimates can be made on the volume of industrial discharges to the bay. Knowledge of industrial chemical processes will give information on the expected kinds of chemicals and a first order estimate of their effluent concentration. The second approach is also qualitative. It involves the identification of a wide range of toxic organic chemicals as part of a toxic screening protocol. Approximately 30 effluents will be examined from plants discharging effluents into the bay and its tidal tributaries. The work includes chemical analysis of the effluents, the development of a set of bioassays and the application of octanal/water partition coefficients, as a measure of bioaccumulation potential. The toxic screening protocol is being developed for the states of Maryland and Virginia under contract with the Monsanto Research Corporation.

The toxic chemical identification involves the use of gas chromatograph/mass spectrometer procedures which are compatible with those of Dr. Robert Huggett of the Virginia Institute of Marine Science who is measuring toxic organic chemicals in sediments and benthic biota from the bay. Both procedures utilize computer capability to identify specific compounds and to store the data base and "finger-prints" of unknown chemicals for future reference.

BASELINE SEDIMENT STUDIES

The Chesapeake Bay Program is conducting an intensive survey of the physical, chemical and biological characteristics of the sediments of the Chesapeake Bay estuary. Surface sediment is being sampled on a kilometer grid in the Maryland portion of the bay and on a 1.4 kilometer grid in the Virginia portion of the bay. The surface sediment samples are being analyzed for particle size distribution, and the content of water, carbon and total sulphur. Maps portraying these parameters are in preparation. In addition, maps showing the areas of sediment accumulation and erosion on the bay bottom have been compiled. Rates of sedimentation have been determined independently using Pb^{210} geochronology and pollen biostratigraphy.

A set of surface sediment samples and cores (1-meter depth) from selected transects across the bay has been analysed for a suite of trace metals. Interstitial water chemistry has been investigated in in the upper meter of sediment at stations from the mouth of the Susquehanna River to the Virginia Capes on a seasonal basis. These data permit calculations of the benthic flux of nutrients and trace metals from the bottom sediment to the estuarine waters. At the same locations, box cores have been collected for benthic infaunal investigations. The integration of the physical and chemical characteristics of the sediment with the benthic infaunal biota will provide better understanding of the role of bottom sediments in estuarine processes.

EXISTING CONDITIONS IN BAY

BAYWIDE SURVEY

The hydrodynamic field survey was designed to provide a data set with which to construct and verify a numerical model of the Chesapeake Bay. The aim was to provide a one-month measurement series of the circulation and driving forces of the Chesapeake Bay System to include: temperature, salinity, current, tide stage, freshwater inflow and meteorological measurements.

Seventy current meters were moored throughout the bay during the month of July. Nearly half of the current meters had salinity and temperature recording capability (primary moorings). The mouth of Chesapeake Bay between the Virginia Capes was the most heavily instrumented, in order to obtain an estimate of the inflow and outflow of the estuary. Instruments were also concentrated on the Cape Charles City - Mobjack Bay transect because of the unique circulation features which have been demonstrated in this area (Figure 3). The Smith Point - Tangier Sound section was designed to measure the outflow from the Potomac as well as the interaction of the Tangier Sound water masses with the bay proper. Single moorings were deployed off Chesapeake Beach, at the Bay Bridge and north of Pooles Island in order to coordinate with the intensive informational base that already exists from previous Chesapeake Bay studies. Additional primary moorings were provided by the United States Geological Survey in the Potomac River and by the Maryland Water Resources Administration near the mouths of the Chester and Patuxent rivers.

Two wind speed and direction recorders were placed on the lower eastern shore of the Chesapeake Bay to fill in the sparse distribution of National Weather Service meteorological stations that now exist for the bay area. In addition, two tide stations were established on the lower eastern shore, because this area was not covered adequately with tide gages.

A comprehensive set of nutrient data for Chesapeake Bay and its tributaries was collected during the period of July 9-16, 1980. This data set will characterize boundary conditions for the bay (bay mouth and tributary mouths) and will also include several transects across the bay. Water movement data, as well as temperature, salinity, chlorophyll a, dissolved oxygen, suspended sediment and nutrients (particulate, dissolved and total nitrogen and phosphorus silicate, ammonia, nitrite, nitrate, organic forms of nitrogen) were collected at thirteen bay transects for the purpose of mass balance and model verification. Sampling at bay transects was performed twice a day at each depth where a current meter was recording water movement. Also, during the eight-day, July field study, sampling was conducted at three-hour intervals for thirty-six

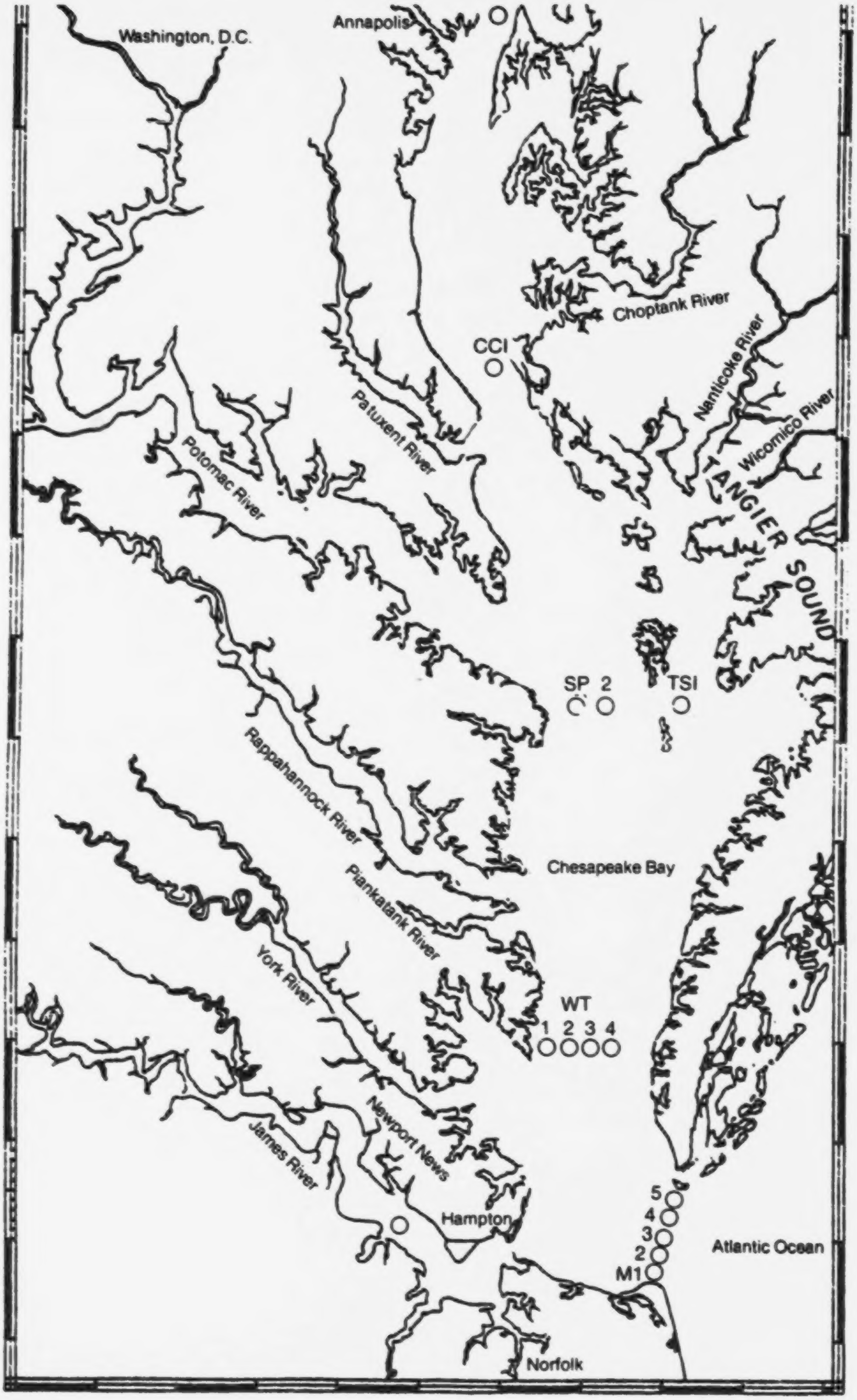
Washington, D.C.
Annapolis
Choptank River
CCI
Patuxent River
Potomac River
Nanticoke River
Wicomico River
TANGIER SOUND
SP 2
TSI
Rappahannock River
Chesapeake Bay
Piankatank River
York River
WT
1 2 3 4
Newport News
James River
Hampton
5
4
3
2
M1
Atlantic Ocean
Norfolk

Figure 3. Moored instrument array positions, June - July 1980.

hours along the transect at the mouth of the Chesapeake Bay. This 36-hour intensive survey was critical to establishing the previously undefined boundary at the mouth of the bay both for nutrients and hydrodynamics.

The set of bay-wide nutrient data collected during the July intensive survey will be used to verify a predictive water quality model of the tidal Chesapeake Bay. In order to make the model function properly, model coefficients or rates must be determined and then read into the model's computer code. These model values will be obtained from the July data as well as from experiments carried out this May and August by bay research institutions. Examples of these model rates are grazing coefficient for zooplankton, benthic dissolved oxygen demand, light extinction coefficient and ratios of N and P to chlorophyll. The model selected for application to the bay is the model developed by Dr. H. S. Chen of the Virginia Institute of Marine Science.

ANALYTICAL APPROACH

WATER QUALITY MODELING

The need for mathematical descriptors of the processes which interact to generate the trophic condition of the Chesapeake Bay system was reflected in the CBP Eutrophication Work Plan of late 1977 (Pheiffer et al. 1977). The plan called for the selection of water quality assessment tools which would develop loads from the tributary basin and "translate material loads into eutrophication levels."

Many predictive models of storm runoff pollution have been developed and reported in the literature over the past decade. They range from complex, computer-based models of rainfall/washoff to a simple statistical relationship between streamflow (or runoff) and aerial pollutant yield rates. Modelers generally classify the former (complex) type as deterministic models and the latter (simple) as parametric models. The trade-offs between these two general classes of modeling approaches have been described as an inverse relationship between the risk of not representing the system versus the difficulty in obtaining a solution (Figure 4). In other words, the level of effort involved with the set-up, calibration, verification and production utilization of a model should be justified by the level of significance required of the results, the quality and extent of the calibration/verification data base and, above all, the availability of the resources necessary to perform the work (Smullen 1980).

The level of modeling selected for the non-tidal drainage basin of Chesapeake Bay is referred to as HSPF or Hydrological Simulation Program in FORTRAN. This state-of-the-art modeling package was developed by EPA Environmental Research Laboratory at Athens, Georgia. The HSPF model is a continuous simulation model which simulates the movement of water and associated pollutants on land surfaces as well as the dispersionary and flow characteristics of conservative and non-conservative constituents in branching stream systems and rivers. Constituents modeled include conservative minerals, temperature, BOD, chlorophyll a, organic and ortho-phosphorus, ammonia, nitrate, nitrite, dissolved oxygen and coliform bacteria. It also considers nutrient cycles, zooplankton and algal growth.

The work plan proposed to be implemented under the EPA/Northern

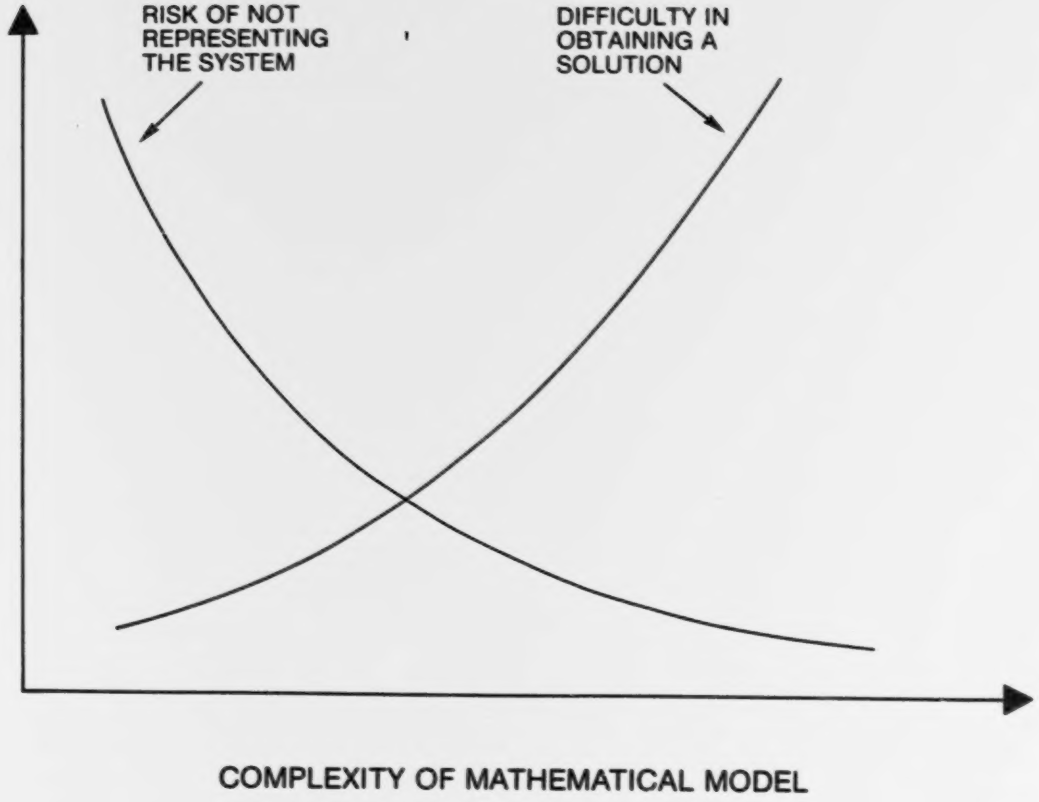

Figure 4 - Tradeoff of Model Complexity With Difficulty in Obtaining a Solution
(Overton and Meadows, 1976)

Virginia Planning District Commission Cooperative Agreement has three major components (Hartigan 1980). The first component will be a comprehensive analysis of the hydrologic and nonpoint source nutrient loading data collected by the investigators for the Pequea, Chester, Patuxent, Occoquan and Ware sites. This 50 to 60 station-years of data will then be used to develop, using continuous simulation model calibration techniques, transferable land use, nonpoint pollution relationships for application to the entire Chesapeake Bay drainage basin (approximately 64,000 square miles).

The second component will be the actual calibration and verification of the HSPF model to the entire drainage basin. This basinwide model will be segmented to provide sufficient loading information to account for point and nonpoint sources of nutrients at the fall lines (Susquehanna, Potomac and James) yet not so detailed that computer costs for long-term simulations would be prohibitive.

The third component of the proposed effort involves the modeling production run phase. The verified basinwide model will be run to produce time series output. This output will then be analyzed to generate loadings, based on existing (1980) and future (year 2000) land use patterns for the entire bay. These loading data are an essential input to a bay-wide water quality model of the tidal Chesapeake.

The bay-wide model covering the bay proper to the head of tide will be employed to identify water quality problem areas based upon fall line loading information. The work will be performed by the Virginia Institute of Marine Scince (VIMS). The approach will be to adapt an existing water quality model to the entire tidal portion of the Chesapeake Bay. The model will not only address the effects of a particular loading scenario, but will be used in an iterative fashion to determine necessary fall line loadings given a particular bay water quality condition.

The model is a two-dimensional, depth averaged, finite element, real time, hydrodynamic, water quality model developed by H.S. Chen at the Virginia Institute of Marine Sciences. The hydrodynamic portion of the model incorporates hydrologic as well as meteorological and astronomical effects. The water quality component addresses the following constituents: phytoplankton, organic nitrogen, ammonia nitrogen, nitrite-nitrate nitrogen, organic phosphorus, inorganic phosphorus, carbonaceous biochemical oxygen demand and dissolved oxygen deficit. In general, the model simulates primary production and its resultant affect on dissolved oxygen concentrations with constants for zooplankton grazing and sediment to water column fluxes of nutrients.

The limiting constraint in using a depth-averaged model is the loss of vertical resolution. This problem is negligible when mixing causes surface to bottom exchange of water mass resulting in a uniform concentration throughout the water column. However, when pressure gradients are strong and stratification is exhibited, dramatic changes in surface to bottom concentrations are possible. It is the latter case in which a better resolution of the problem is needed.

The problem becomes one of testing the validity of depth averaging in areas delineated as having a dissolved oxygen problem. In order to accomplish this, a three-dimensional real time hydrodynamic model is being developed by Camp, Dresser and McKee. This model, like the VIMS model, is also a finite element model. The model will be used to investigate the nature of the hydrodynamics in areas determined to have a dissolved oxygen problem using the VIMS model. If vertical mixing cannot be assumed, then the depth averaged concentration will be vertically profiled using historical data.

The key indicator used in this approach to define the existence of a eutrophication problem will be dissolved oxygen concentrations. In order to assess possible biota effects as the result of depressed DO concentrations, an indices approach will be taken. A preliminary report on selected and developed indices for use in the detection, measurement and assessment of estuarine nutrient enrichment was prepared in October of 1979 by the Chesapeake Research Consortium and will be used for this purpose.

TOXIC RISK ASSESSMENT

As a final component of the program, the toxic chemicals of concern will be subjected to a risk analysis. These chemicals are being identified in the sediments, water and selected biota of the bay and from effluents that enter the bay. Considerable background data are being developed on the sources, loadings to the tidal estuary and transport and fate of toxic chemicals in the bay. This information will be used to develop an exposure assessment model which will estimate the concentration of a toxic chemical at a specified location and time to the extent possible in the estuary. This model, coupled with information on toxicity of specified compounds to selected organisms and knowledge about the distribution and abundance of organisms, will be the basis for the risk assessment.

Three levels of risk assessment are to be used. All chemicals of concern will be evaluated by the automated methods which constitutes level one. Lists of toxic chemicals will be compared to the chemicals of concern. Chemical Abstract System (CAS) numbers will be used in the searches.. The lists of chemicals will include the proposed and established water quality criteria chemicals and other lists of chemicals from various resources which include toxicity data that can be easily stored on a computer system. Only select chemicals will be evaluated by the second level of risk assessment. The second level involves a thorough literature search and review for select chemicals of concern. When data are still deficient and/or there is reason for extra concern, then the third level of assessment will be included. The third level involves a structure-activity relationship approach. The structure-activity relationship approach invlolves the generation of analogs and/or metabolites followed by a literature search and review of these compounds. Principles of chemistry and toxicology are used to evaluate the literature data and to estimate the hazard of the chemical of concern.

SUMMARY

The bay-wide methodology as presented here characterizes the system as to what is coming into the system, what is currently in the system, how it moves about within the system and an approach to assess its impacts. In the toxics as well as the nutrient program areas, the framework is to identify the present distribution, current impacts and behavior and fate of toxics and nutrients. This information will provide a baseline description of the estuarine system against which future changes can be measured, and possible control measures assessed.

REFERENCES

Hartigan, J.P.,Jr. A modeling study of nonpoint pollution loadings and transport in the Chesapeake Bay basin. Work Plan of Northern Virginia Planning District Commission; 1980.

Lang, D.J.; Grason, D. 1980. Water quality monitoring of three major tributaries to the Chesapeake Bay - interim data report. U.S. Geological Survey Water Resources Investigations; 1980: 80-78.

Mason, B.J.; McFadden, J.E. Landuse and point sources in the Chesapeake Bay Study area. Annapolis, MD: U.S. Environmental Protection Agency, Chesapeake Bay Program. U.S. E.P.A. Contrib. 68-01-4144; 1980.

Overton, D.E.; Meadows, M.E. Stormwater modelling. New York: Academic Press; 1976.

Pheiffer, T.H. et al. Eutrophication work program for Chesapeake Bay; 1977. Report of Eutrophication Work Group.

Pritchard, D.W. Observations of circulation in coastal plain estuaries. Lauff, G. ed. Estuaries Washington, DC: American Association Advancement Science. 1967: 37-44.

Smullen, J.E. A water quality assessment methodology for the Chesapeake Bay watersheds. Working Paper, Chesapeake Bay Program, EPA; 1980.

U.S. Environmental Protection Agency, Office of Research and Development. Research Summary, Chesapeake Bay. 1980; EPA-600/8-80-019.

Water Quality of the Upper Great Lakes, IJC Report to the Governments of Canada and the U.S., May 1974; 91 p.

CHAPTER 2

RESTORATION OF FRESHWATER INFLOW TO AN ESTUARY IN CONJUNCTION WITH URBAN DEVELOPMENT

HISTORICAL BACKGROUND AND OVERVIEW OF PLAN FOR RESTORING FRESHWATER INFLOW TO AN ESTUARY IN CONJUNCTION WITH URBAN DEVELOPMENT

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ABSTRACT

The Marco Island development proceeded concurrently with changing wetland regulations. Permits to construct sold lands were denied. The developer has proposed a substitute plan calling for development of 1,500 acres of uplands and 2,500 acres of wetlands located near the estuary. A key feature of the new plan is the proposed restoration of freshwater inflow to fringing estuarine wetlands impacted by prior construction of roads and drainage works. Technical reports upon which this plan is based are presented.

BACKGROUND AND STATUS OF ORIGINAL DEVELOPMENT PLANS

Marco Island is located in a mangrove estuarine area on the southwest coast of Florida approximately 10 miles south of Naples, 100 miles due west of Miami, and 20 miles northwest of Everglades National Park (Figure 1). When the Marco Island project started in 1964, State and Federal regulations encouraged the development of waterfront communities in mangrove areas. Initial plans called for dredging and filling large portions of the 19,500 acre original ownership area (Figure 2). The initial phase of the overall 19,500 acre plan consisted of Marco Island itself (7,000 acres). Dredge and fill permits to construct the first 22 percent (1,550 acres) of the island were routinely granted in 1964 by State and Federal agencies. In 1969, the Corps of Engineers approved the completion of the next 31 percent (2,200 platted acres) of the community.

Because in 1969 over 75 percent of the Marco Island lots were already sold, the Corps acknowledged the continuing sale of lots on the remaining 47 percent (3,300 platted acres) of the island. They also acknowledged continuing sales in a 2,500 acre newly platted mainland area known as the Collier-Read tract. To accomodate new regulatory concerns, however, the Corps and the developer agreed that no additional lots would be sold on 10,000 additional unplatted acres until after all development permits were obtained.

In 1972, according to new State regulations, the Governor and Cabinet of the State of Florida formalized an environmental agreement with Deltona. In return for State approvals to complete the development of Marco Island the developer agreed to deed over 4,000 acres of mangrove wetlands and

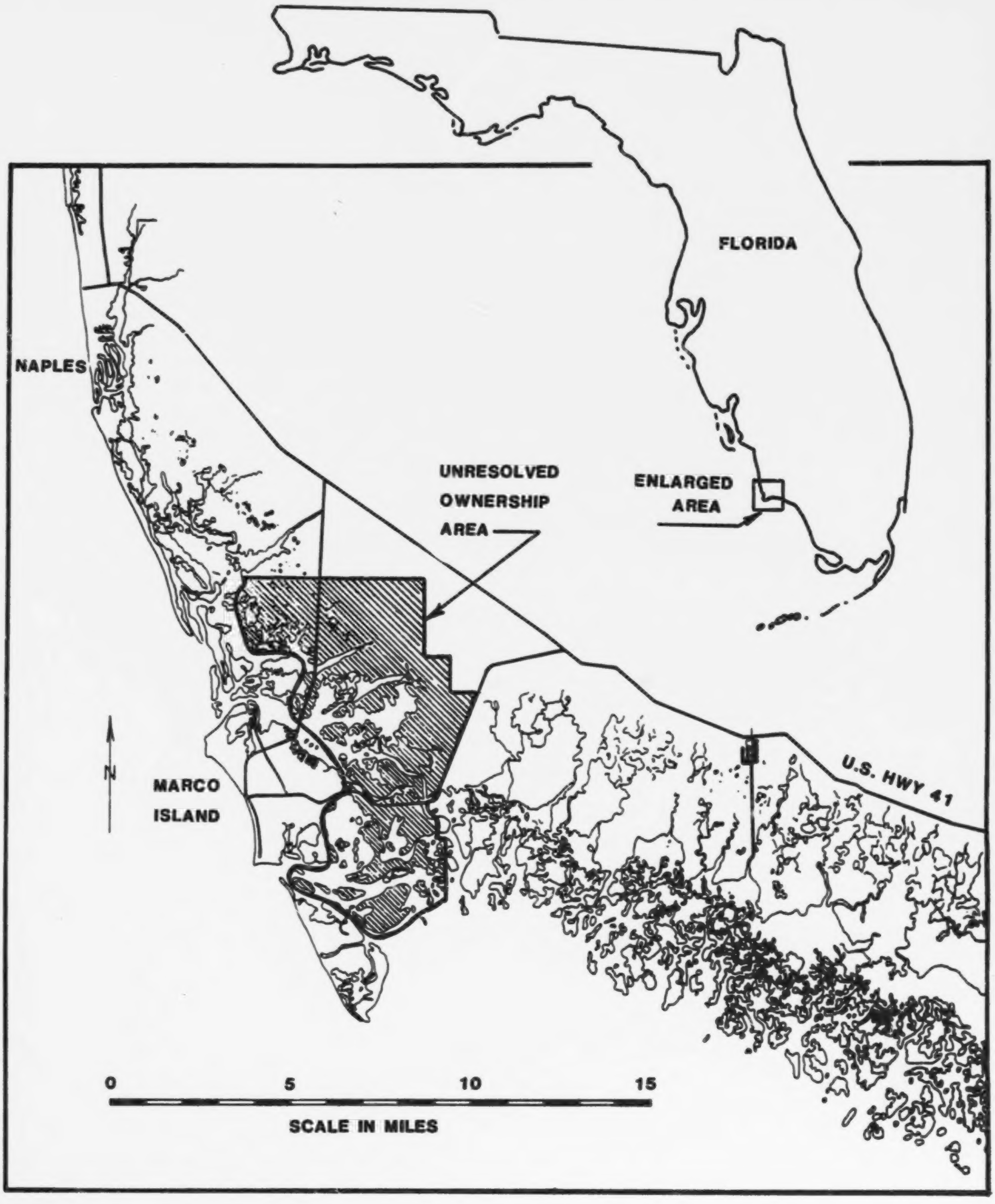

FLORIDA
ENLARGED AREA
UNRESOLVED OWNERSHIP AREA
NAPLES
MARCO ISLAND
N
U.S. HWY 41
0
5
10
15
SCALE IN MILES

FIGURE 1. LOCATION

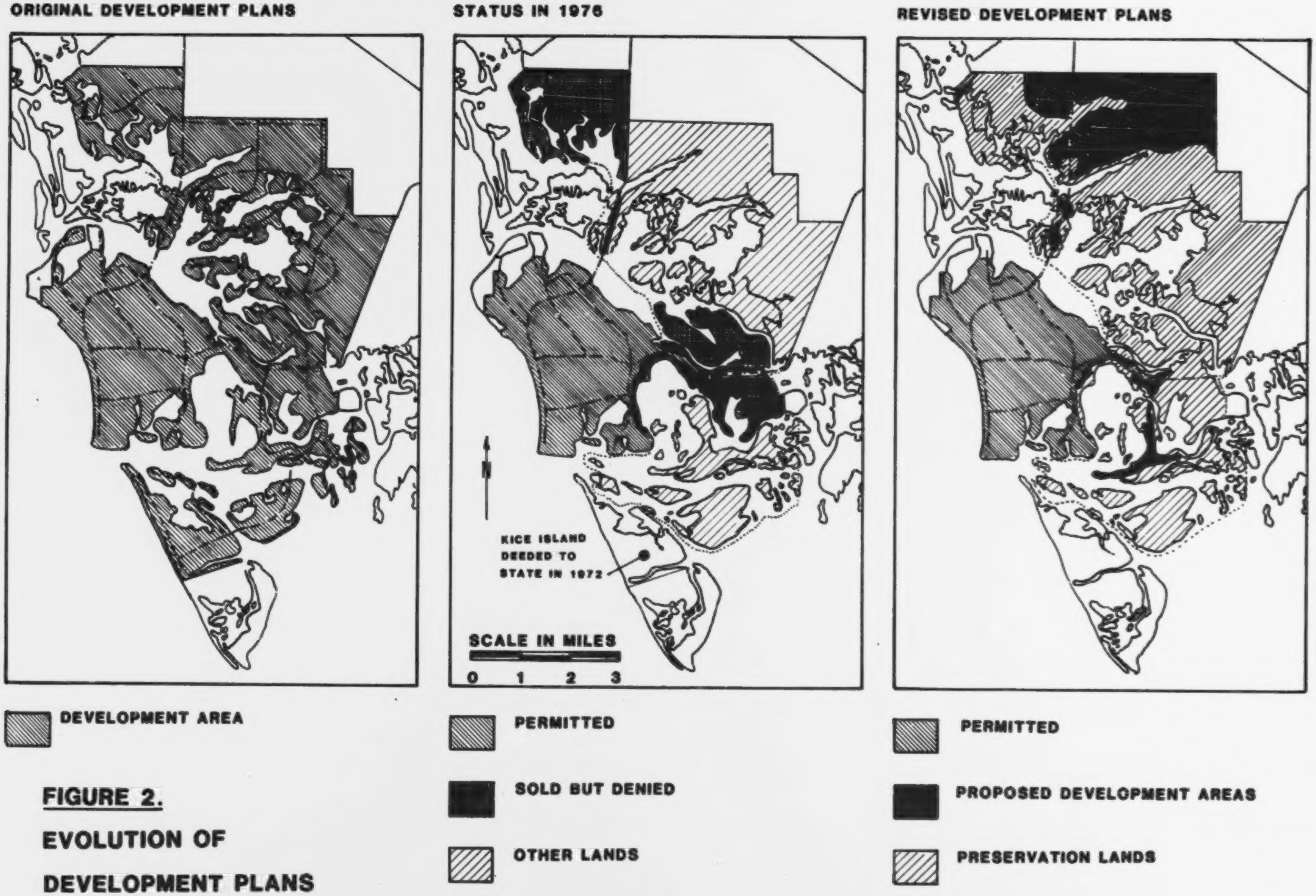

ORIGINAL DEVELOPMENT PLANS
STATUS IN 1976
REVISED DEVELOPMENT PLANS
N
KICE ISLAND DEEDED TO STATE IN 1972
SCALE IN MILES
0 1 2 3
▨ DEVELOPMENT AREA
▨ PERMITTED
■ SOLD BUT DENIED
▨ OTHER LANDS
▨ PERMITTED
■ PROPOSED DEVELOPMENT AREAS
▨ PRESERVATION LANDS

FIGURE 2.
EVOLUTION OF DEVELOPMENT PLANS

estuarine bay bottoms into State ownership. In 1974 the developer satisfied new requirements of Federal law and received water quality certification for the remaining unpermitted canals on Marco Island. In 1976, the Corps relied on 1975 regulations to grant permits for 16 percent (1,120 platted acres), and to deny permits for the remaining 31 percent (2,170 platted acres) of the Marco Island plan (Figure 2).

OVERVIEW OF REVISED DEVELOPMENT PLANS

Shortly after the 1976 Corps decision, the developer purchased three sections of lands immediately north of his original ownership. Vegetation mapping and ecosystem analysis of the entire unpermitted ownership began (Figure 3). At the same time urban planners started work on a development plan that aimed to achieve many objectives.

A. The maintenance of the estuarine ecosystem required preservation of essentially all estuarine bays and surrounding mangrove areas. Freshwater inputs to the estuary had to be maintained or enhanced.

B. Attractive substitute waterfront lots had to be provided for customers denied their lots by the Corps in 1976.

C. The project had to mitigate the financial losses resulting from the 1976 denials. Therefore, additional residential units beyond those specifically denied had to be included in the plan.

D. The new project had to be linked to the existing Marco community for marketing purposes and for efficiency in providing community ammenities such as transportaion, potable water, sewer, emergency services, commercial and business areas, education facilities, recreation, health care.

The resulting revised plan of development for Deltona's 17,000 acre Marco ownership is restricted to 4,000 acres comprised of 1,500 acres of uplands and 2,500 acres of interior wetlands. The remaining 13,000 acres of wetland ownership will be preserved (Figure 4).

RESTORATION OF FRESHWATER INFLOW TO THE ESTUARY

Inland from the Marco estuary the topography is flat with elevations rising at approximately one foot per mile. Before railroads, highways, agriculture, and large scale inland land development, the water table was near the ground surface and extensive areas were flooded for portions of the year. Freshwater flows to the estuary were the gradual and steady result of surface sheet flow and ground water movement fed by a large interior basin (Figure 5).

Aerial photos, on-site inspection, and government publications (McCoy 1972; Carter et al. 1973; Swayze and McPherson 1977) show that surface flows from interior areas northeast or "upstream" of the proposed development site have been altered by land development drainage, agricultural irrigation and drainage, and road and barrow ditch construction. These factors have lowered the water table and short-circuited surface flows directly to the estuary.

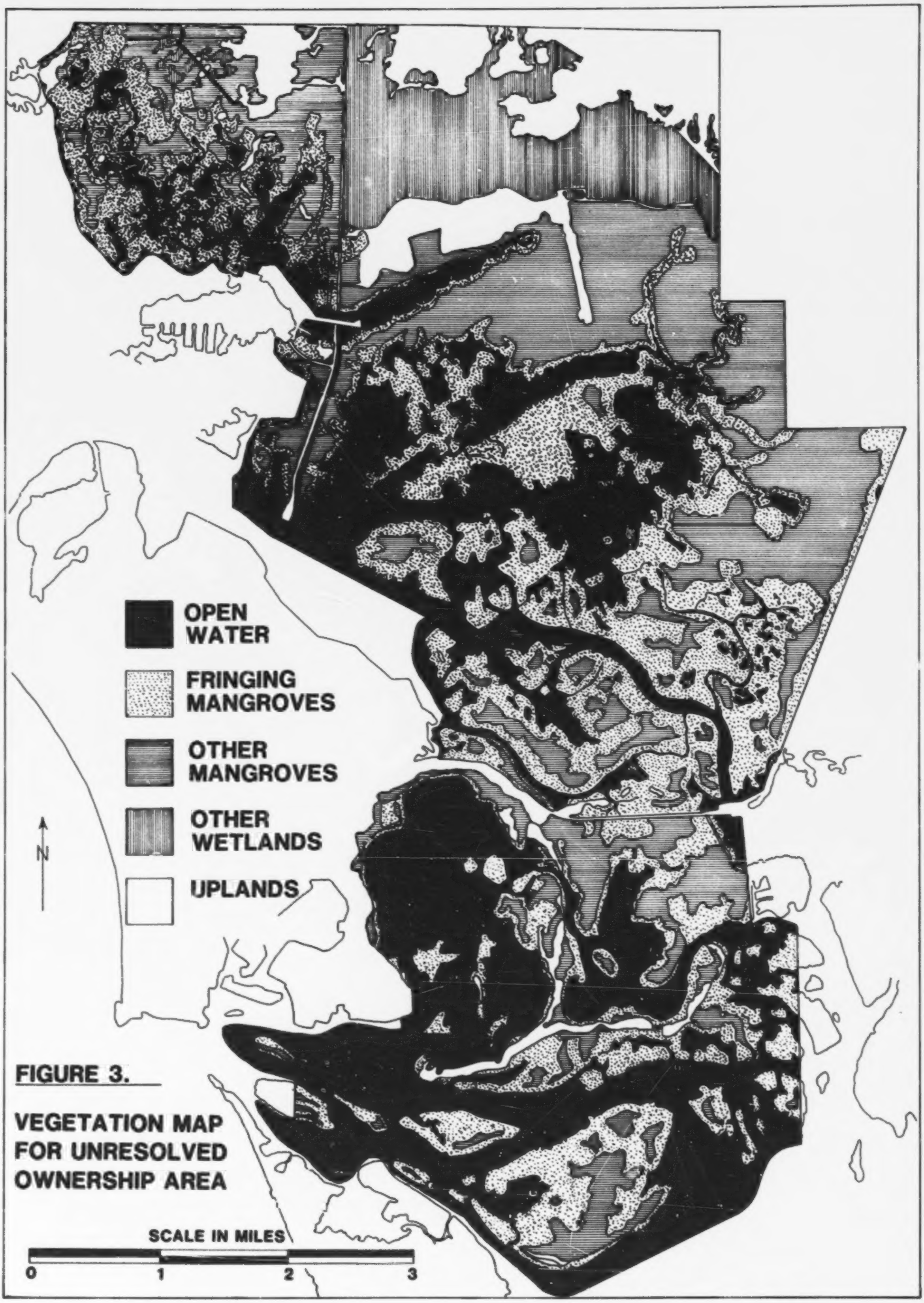

OPEN WATER
FRINGING MANGROVES
OTHER MANGROVES
OTHER WETLANDS
UPLANDS
N
SCALE IN MILES
0
1
2
3

FIGURE 3.

VEGETATION MAP FOR UNRESOLVED OWNERSHIP AREA

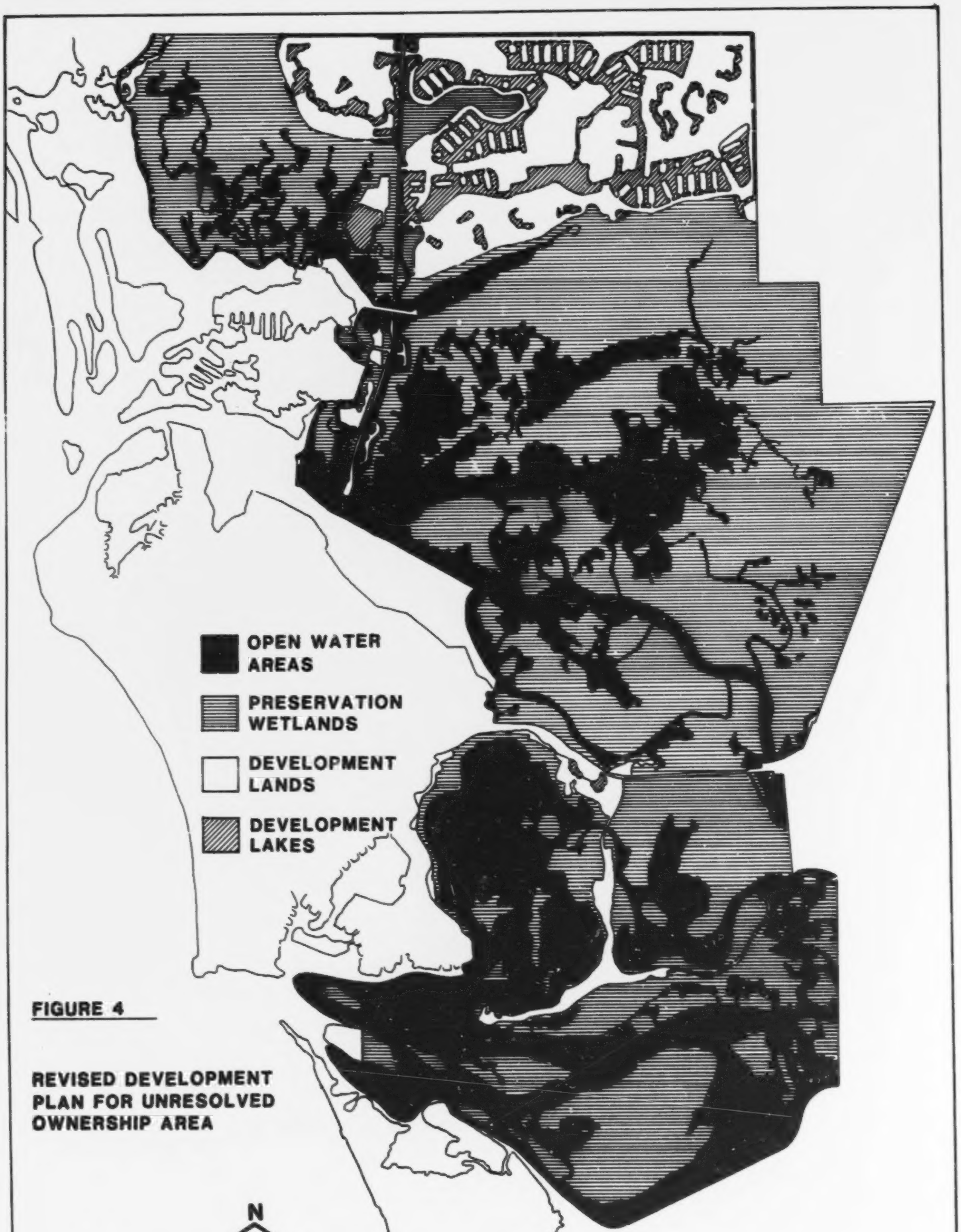
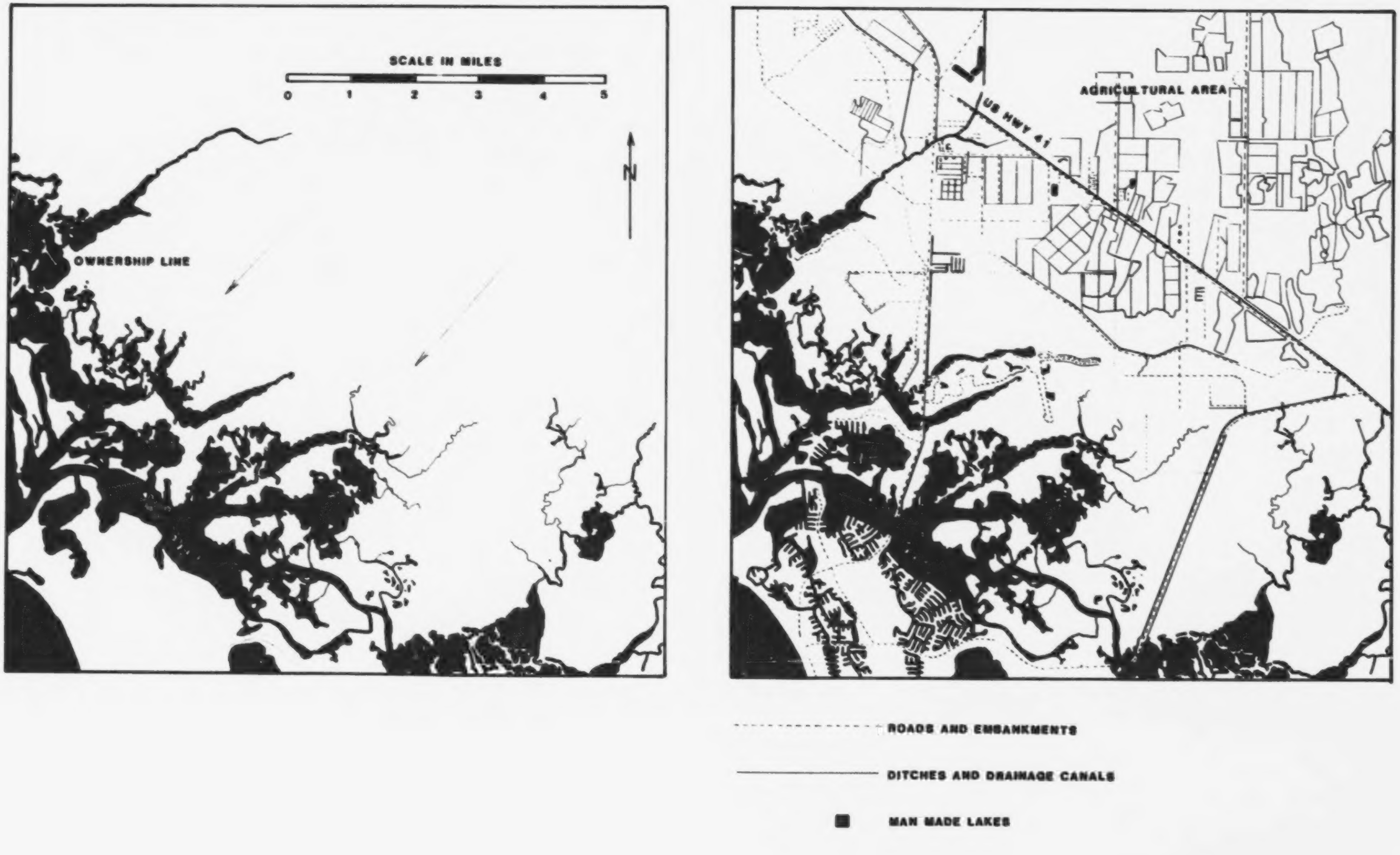

OPEN WATER AREAS
PRESERVATION WETLANDS
DEVELOPMENT LANDS
DEVELOPMENT LAKES
N
SCALE IN MILES
0
1
2

FIGURE 4

REVISED DEVELOPMENT PLAN FOR UNRESOLVED OWNERSHIP AREA

FIGURE 5.



ORIGINAL SHEET FLOW DRAINAGE

PRESENT CHANNELIZED DRAINAGE

SCALE IN MILES
0
1
2
3
4
5
N
OWNERSHIP LINE
AGRICULTURAL AREA
US HWY 41
ROADS AND EMBANKMENTS
DITCHES AND DRAINAGE CANALS
MAN MADE LAKES

Drainage patterns on and immediately adjacent to the proposed Unit 24/Unit 30 development site were altered by early (1926) railroad construction, early highway construction (Belle Meade grade), drainage ditches (adjacent to State Road 92 and Port au Prince subdivision), golf course and airport construction, and by agricultural drainage practices. On a local basis these factors raised the water table in some areas creating probable vegetation changes from saline to fresh. In other areas these factors channelized surface and groundwater flows directly to the estuary resulting in certain fringing estuarine areas being cut off from historical freshwater flows. In addition, the channelized flows changed the timing and quality of freshwater inputs to the estuary.

The proposed plan for restoring freshwater inputs to the estuary is based upon blocking all channelized flows that presently leave the site. Real estate lakes will be constructed in uplands and in impacted freshwater wetlands immediately upgradient from the estuary. Lake excavation materials will be utilized to fill adjacent areas for roads and dwellings. A low levee will isolate the lake from the estuary. Water levels in the lake will seasonally vary between +1.5 and 2.0 (NGVD) duplicating present water table fluctuations. The lake will be fed by rainfall, surface runoff from adjacent development areas, and by groundwater inflow. The lake will discharge by evaporation, groundwater outflow, and over adjustable weirs to spreader ditches which will overflow into preservation estuarine wetlands. Freshwater outflow from the lake will thus be delivered to the estuary via sheet flow across preservation wetlands. Upgradient surface flows from offsite will be routed via grassed swales around the development and supplied to spreader ditches and then via wetland sheet flow to the estuary (Figures 6 and 7).

In this particular area of Florida there is a natural berm near the water's edge. This berm causes shallow impoundment of extensive areas. The berm is overtopped by high spring tides. The shallow impounded area is therefore filled by rainfall, surface runoff from upgradient, and by overtopping spring tides. Surface discharge from the man-made lake will be supplied via spreader ditches into this shallow natural impoundment. Slow migration across this impounded area to the estuary will allow polishing and treatment of outflows prior to arrival at the estuary.

All the real estate lakes will be interconnected allowing the flexibility of routing surface discharge to the adjustable weir and spreader ditch immediately upgradient from particular fringing wetlands that can be improved by freshwater inflow. The lake system is designed to initially retain a 100-year, 24-hour storm. Weirs will be adjustable to allow subsequent discharge over a protracted period thus simulating historical freshwater inputs to the estuary. During dry periods groundwater inputs to the lake will be routed to spreader ditches and then to wetland surface flow instead of lost to drainage ditches as at present.

CONCLUSION

This project is not intended to set a precedent for wetland development. The goal is to achieve a compromise where changing government regulations have halted an ongoing project. Development of 1,500 acres of uplands and 2,500 acres of

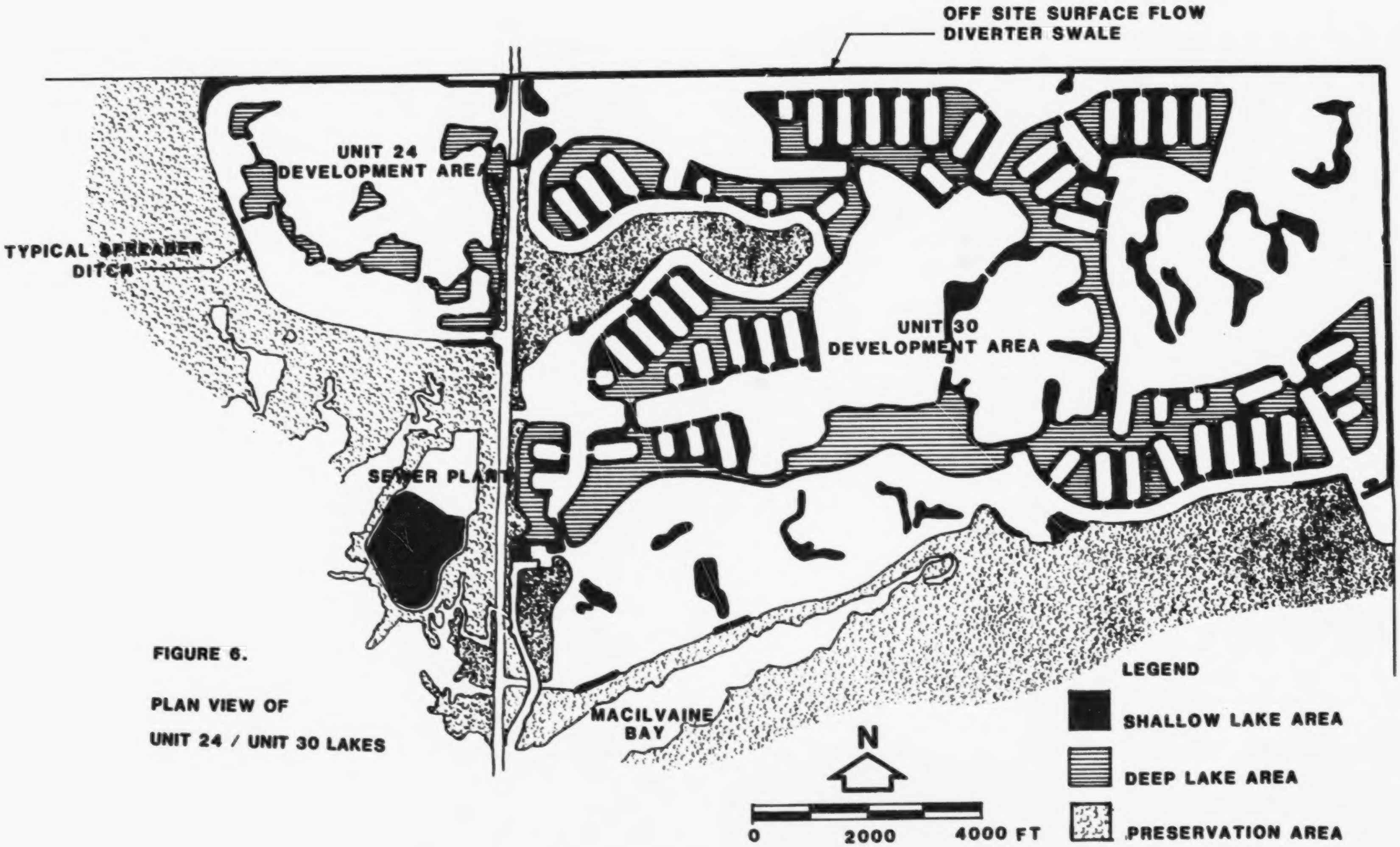

OFF SITE SURFACE FLOW DIVERTER SWALE
UNIT 24 DEVELOPMENT AREA
TYPICAL SPREADER DITCH
UNIT 30 DEVELOPMENT AREA
SEWER PLANT
MACILVAINE BAY
N
0
2000
4000 FT
LEGEND
SHALLOW LAKE AREA
DEEP LAKE AREA
PRESERVATION AREA

FIGURE 6.

PLAN VIEW OF

UNIT 24 / UNIT 30 LAKES

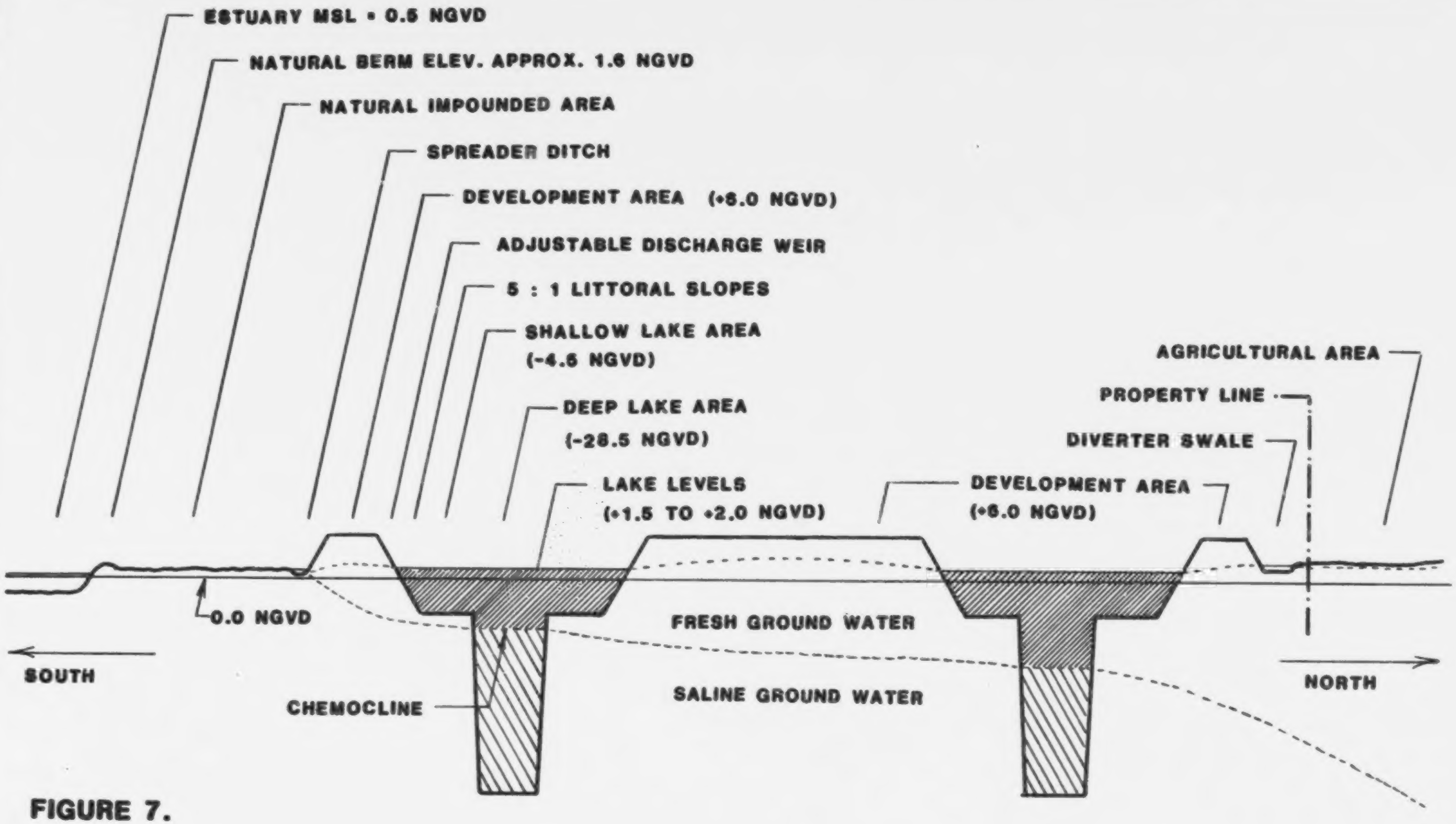

ESTUARY MSL = 0.5 NGVD
NATURAL BERM ELEV. APPROX. 1.6 NGVD
NATURAL IMPOUNDED AREA
SPREADER DITCH
DEVELOPMENT AREA (+6.0 NGVD)
ADJUSTABLE DISCHARGE WEIR
5 : 1 LITTORAL SLOPES
SHALLOW LAKE AREA (-4.5 NGVD)
DEEP LAKE AREA (-28.5 NGVD)
LAKE LEVELS (+1.5 TO +2.0 NGVD)
AGRICULTURAL AREA
PROPERTY LINE
DIVERTER SWALE
DEVELOPMENT AREA (+6.0 NGVD)
0.0 NGVD
FRESH GROUND WATER
SALINE GROUND WATER
CHEMOCLINE
SOUTH
NORTH

FIGURE 7.

UNIT 24 / UNIT 30 LAKES
SCHEMATIC CROSS SECTION

interior wetlands is planned. A key feature of the plan is hydraulic design to restore freshwater inflow to fringing estuarine wetlands impacted by prior construction of roads and drainage works. The following sections of Chapter Two provide technical information upon which this plan is based.

A. Floral Description of Marco Shores Development Site. Eric Heald.

B. Meromixis in a Coastal Zone Excavation. Charles M. Courtney.

C. The Ground Water Flow System in the Vicinity of Marco Island, Florida. Vincent P. Amy.

D. Surface Water Flow from a South Florida Wetlands Area. J. van de Kreeke and Ernest Daddio.

E. Water Budget and Projected Water Quality in Proposed Man-made Lakes near Estuaries in the Marco Island Area, Florida. Wayne C. Huber and Patrick L. Brezonik.

LITERATURE CITED

Carter, M. et al. Ecosystems analysis of the Big Cypress Swamp and estuaries. U.S. Environmental Protection Agency, Region IV; 1973.

McCoy, J. Hydrology of western Collier County, Florida. Prepared by U.S. Geological Survey for the State of Florida Department of Natural Resources; 1972 Report of Investigations No. 63.

Swayze, L; McPherson, B. The effect of the Faka Union Canal System on water levels in the Fakahatchee Strand, Collier County, Florida. U.S. Geological Survey Water Resources Investigations 77-61 prepared in cooperation with the National Park Service; 1977.

FLORAL DESCRIPTION OF MARCO SHORES DEVELOPMENT SITE

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Program Director
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Miami, Florida

The proposed development tract covers the land lying between MacIlvaine Bay in the south and the old "Belle Meade Grade" in the north and extends 4,827 m from east to west. The western boundary is State Road 951. The tract includes some farmed land in the northeast corner, a golf course and airport, and an excavated lake known as Lake Marco Shores.

The flora of the tract was examined from the air and on the ground in October and November 1976. Aerial photography from 1962 and 1974 at a scale of 2.54 cm = 304.8 m was used to locate various large-scale plant associations. Ground observation confirmed the photo registry and was used to describe details of plant cover not evident on the aerials. Exotic plants such as *Melaleuca* and Brazilian pepper were largely absent from this tract. Fire has had a serious effect on the plants and soils of the tract as evidenced by numerous burnt out hammocks and pine stands. The results of the study are presented in Figure 1 and Table 1 which provide a map and list of visually dominant plant groupings and also by Figure 2 which subdivides the area according to duration of flooding.

To interpret Figure 1, associations or features have been lettered according to the following key: A - Pineland associes; B - Pine barrens; C - Swale with mixed grasses, rushes and scrub buttonwood; D - *Eleocharis* (tall phase) and freshwater mangroves; E - *Eleocharis* (short phase) and freshwater mangroves; F - Pothole ponds; G - *Chara* ponds; H - Buttonwood hammocks and strands on "Gandy peat" soil; I - West Indian hardwood hammock; J - Cresent Lake; K - Red mangrove berm that experiences daily tidal influence; L - Mangrove impoundment and possible weekly tidal; M - Farmland; N - Impacted tidal creek system; O - Golf course and airport; P - Lake Marco Shores; Q - Polyhaline mangrove; R - Freshwater red mangrove forest; S - Black rush (*Juncus roemerianus*); T - *Fimbristylis-Spartina*.

The present mangrove and emergent vegetative associations north of the main east-west levee extension are depositing their leaf, seed and twig fall in situ and this is leading to a rapid elevation of soil profiles. The Water Surveillance Branch for Region IV of The U.S. Environmental Protection Agency (USEPA), has collected field data on water quality and primary production in this area (Cavinder 1979). In pure *Eleocharis* stands they found a live standing crop biomass of 295 g/m^2 (ash free dry weight) with 136 g/m^2 of dead material. The accretion of material within the marsh has been hastened by a heavy growth of *Chara* in the permanent open ponds. The USEPA and Courtney (1979) have reported high rates of respiration

Pine-Cabbage Palm Association

Slash pine	*Pinus elliottii*
Cabbage palm	*Sabal palmetto*
Saw palmetto	*Serenoa repens*
Blechnum	*Blechnum serrulatum*
Red bay	*Persea borbonia*
Saltbush	*Baccharis* sp.
Wax myrtle	*Myrica cerifera*
Buttonwood	*Conocarpus erecta*
Sawgrass	*Cladium jamaicense*
Poison ivy	*Toxicodendron radicans*
Sumac	*Rhus* sp.
Possum grape	*Cissus sicyoides*
Cypress	*Taxodium distichum* (very uncommon)
Snowberry	*Chiococca pinetorum*
Myrsine	*Myrsine guianensis*
Rusty lyonia	*Lyonia ferruginea*
Broomsedge	*Andropogon* sp.
Cordgrass	*Spartina bakeri* (low edges)
Redtop grass	*Rhynchelytrum repens*
Beakrush	*Rhynchospora tracyi*
Muhly grass	*Muhlenbergia capillaris*
Sand spurs	*Cenchrus* sp.

Dwarf Buttonwood-Sesuvium Association

Buttonwood	*Conocarpus erecta* (carpet form .6 m tall)
Sea purslane	*Sesuvium portulacastrum*
Saltgrass	*Distichlis spicata* (sparse)
Key grass	*Monanthochloe littoralis* (localized)
Black rush	*Juncus roemerianus* (short and stressed)
Slash pines	*Pinus elliottii* ("lighter" stumps only)
Glasswort	*Salicornia* sp.
Love vine	*Cassytha filiformis*
Blunt spikerush	*Eleocharis obtusa*
Fringe rush	*Rhynchospora grayii*

Buttonwood Hammocks-*Eleocharis* Association

Spike rush	*Eleocharis cellulosa* (short phase)
Buttonwood	*Conocarpus erecta* (medium development 1.2-6.1 m)
Cabbage palm	*Sabal palmetto* (many dead, others surviving)
Black rush	*Juncus roemerianus* (hammock edges)
White indigo berry	*Randia aculeata*
Saffron plum	*Bumelia celastrina* (common)
Spanish stopper	*Eugenia myrtoides*
Leatherfern	*Acrostichum aureum* (in shade)
Leatherfern	*Acrostichum danaeaefolium* (in open areas)
Christmas berry	*Crossopetalum* sp.
Rubber vine	*Rhabdadenia biflora* (wet situations)
Wild allamanda	*Urechites lutea* (dry situations)
Love vine	*Cassytha filiformis* (recently burned areas)
Sand cordgrass	*Spartina bakeri* (drier hammock edges)
Wire grass	*Fimbristylis* sp.
Seagrape	*Cocoloba uvifera* (uncommon)
Black mangrove	*Avicennia nitida* (occasional)
Strangler fig	*Ficus aurea*

Eleocharis-Dwarf Red Mangrove Association

Spike rush	*Eleocharis cellulosa*
Red mangrove	*Rhizophora mangle* (advanced age, but low)
Chara	*Chara hornemanni* (sparse)
Widgeon grass	*Ruppia maritima* (sparse)
Buttonwood	*Conocarpus erecta*
Banded airplant	*Tillandsia flexuosa*

Buttonwood Embankments

Buttonwood	*Conocarpus erecta* (to 9.1 m)
Red mangrove	*Rhizophora mangle* (marginal)
White mangrove	*Laguncularia racemosa*
Cabbage palm	*Sabal palmetto*
Saffron plum	*Bumelia celastrina*
Gumbo limbo	*Bursera simarubra* (uncommon)
Rubber vine	*Rhabdadenia biflora*
Leatherfern	*Acrostichum aureum*
Leatherfern	*Acrostichum danaeaefolium*
Twisted air plant	*Tillandsia circinata*
Banded air plant	*Tillandsia flexuosa*
Reflexed air plant	*Tillandsia balbisiana*
Stiff-leaved air plant	*Tillandsia fasciculata*
Butterfly orchid	*Encyclia* (=*Epidendrum*) *tampense*
Pepper vine	*Ampelopsis arbarea*
Poison ivy	*Toxicodendron radicans*

Red Mangrove-Chara-Open Pond Association

Red mangrove	*Rhizophora mangle* (to11 m tall)
Chara	*Chara* sp. (dense growth in 50-60 cm water)
Giant air plant	*Tillandsia utriculata*
Jointgrass	*Paspalum distichum*
Cattail	*Typha angustifolia*

Mixed Mangrove-Polyhaline Phase

Red mangrove	*Rhizophora mangle*
Black mangrove	*Avicennia nitida*

Eleocharis-Black Rush Association

Black rush	*Juncus roemerianus* (medium height to1.2m)
Spike rush	*Eleocharis cellulosa*
Prickly cord grass	*Spartina spartinae* (scattered)
Wire grass	*Fimbristylis castaneus*
Red mangrove	*Rhizophora mangle* ("spider" form)
Buttonwood	*Conocarpus erecta* (small hammock & strands)
Leatherfern	*Acrostichum danaeaefolium*

Black Rush-*Spartina* Association

Black rush	*Juncus roemerianus* (tall phase to1.7m)
Prickly cord grass	*Spartina spartinae* (dense, tall phase)
Wire grass	*Fimbristylis castaneus* (higher margins)
Sawgrass	*Cladium jamaicensis* (drier sites, declining)
Buttonwood	*Conocarpus erecta*
Spike rush	*Eleocharis caribaea*

TABLE 1 A LISTING OF THE MAJOR PLANT ASSOCIATIONS OF THE MARCO SHORES TRACT BASED ON VISUAL DOMINANCE

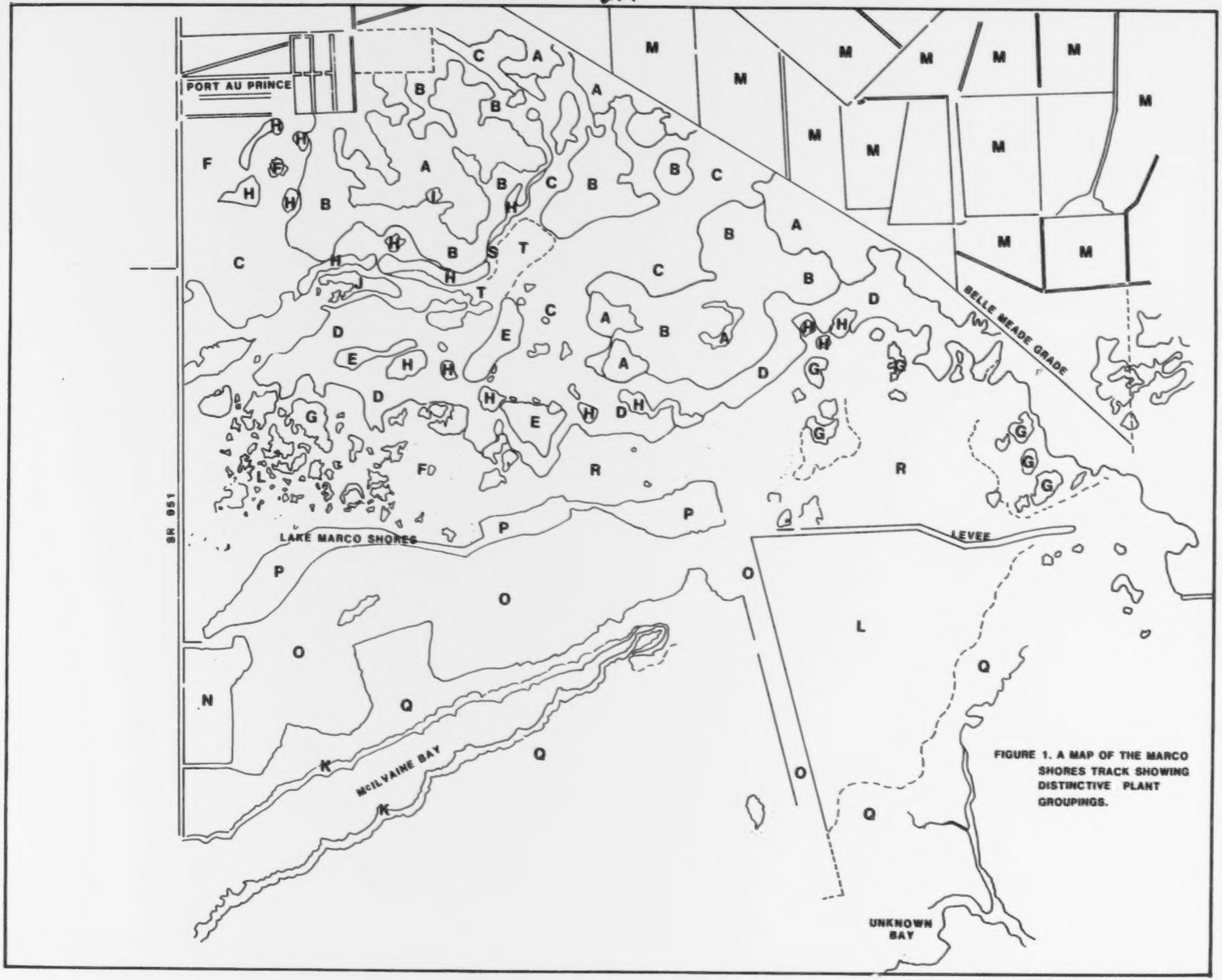
PORT AU PRINCE
BELLE MEADE GRADE
LAKE MARCO SHORES
LEVEE
SR 951
McILVAINE BAY
UNKNOWN BAY

FIGURE 1. A MAP OF THE MARCO SHORES TRACK SHOWING DISTINCTIVE PLANT GROUPINGS.

relative to production in community metabolic studies of the standing water in these ponds and marshes. Periodic severe oxygen depletion was observed.

Examination of plant community structure (Figure 1), aerial photography and water depths strongly suggest that the area north of the east-west levee, airport, and golf course was a freshwater habitat that was invaded by salt water species such as the red mangrove which have the ability to live in "hard" freshwater.

South of the artificial east-west levee and east of the airport runway lies a weak tidal mangrove community occupying a shallow basin approximately 119 hectares (ha) in area. It is dominated by black mangroves up to 6 m in height with a considerable admixture of smaller reds and whites. Large buttonwood snags along the dashed line between L and Q (Figure 1) attest to a formerly fresher regime, and a comparison of 1952, 1963 and 1974 aerial photography suggests a rapid continuing invasion of mangroves there, as well as to the north of the levee. Most of the basin remains shallowly inundated for much of the year, as a result of direct rainfall combined with relatively frequent though weak tidal penetration.

Tides probably penetrate the 119-ha basin on a seasonal basis by overflowing laterally from the large tidal creek that flows north from the head of Unknown Bay. Tidal waters enter also on a more frequent basis via a series of shallow creeks and swales which penetrate the "lip" of the basin in the southeast. These also provide the main drainage from the basin.

A build-up of flocculent material and leaf debris is not strongly evident in the 119-ha basin. This suggests that either (a) production of these materials is very low, or (b) tidal export is adequate to prevent accumulation of particulates. We suggest that the latter case prevails, and that there is a gradual net movement of particulates in a southeasterly direction through the basin or "impoundment" rim (shown as dashed line in Figure 1) toward the head of Unknown Bay.

Figure 2 divides the 1,011-ha area south of the Belle Meade grade into four main zones based on the present duration of flooding. Zone 1 includes the living pinelands and adjacent sand barrens. These areas are infrequently flooded in their upper elevations and to depths of only about 13 cm at the lowest barren sites during the period June through September in years of normal rainfall. Zone 1^1 lies at a somewhat lower elevation than the lowest level of zone 1 but higher than zone 2. Zone 1^1 supports short spike rush, *Eleocharis*, which grows in water estimated to average 28 cm in depth. This area is called "light rush" to conform with the terminology of Reark (1960; 1961) and Van Meter (1965). Flooding in zone 1^1 probably lasts from June through December at the present time. Zones 1 and 1^1 cover about 267 ha.

Zone 2, variously covered by *Eleocharis*, red mangroves, rushes and salt joint grass, *Paspalum distichum*, lies at a still lower elevation. Measurement of water marks and periphyton growth on plant stems indicate an average maximum depth of flooding of about 38 cm, so these areas must lie about 10 cm lower than the zone 1^1 lands and about 25 cm lower than the seaward margins of the pineland barrens. Zone 2 is a region of "heavy rush" which probably remains flooded, at least with some water, during the

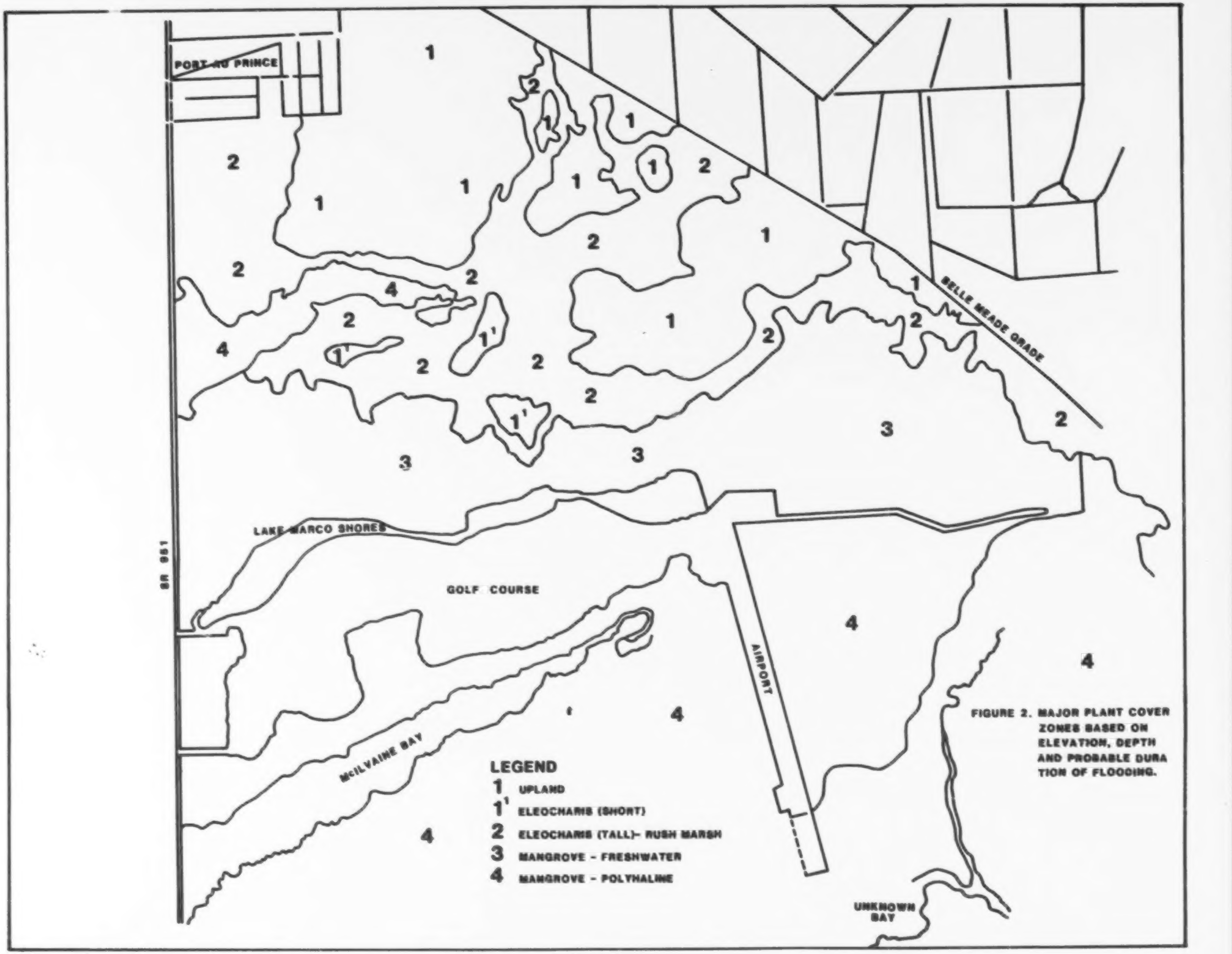
PORT AU PRINCE
BELLE MEADE GRADE
SR 951
LAKE MARCO SHORES
GOLF COURSE
AIRPORT
McILVAINE BAY
UNKNOWN BAY
1
1'
2
3
4
LEGEND
1 UPLAND
1' ELEOCHARIS (SHORT)
2 ELEOCHARIS (TALL)- RUSH MARSH
3 MANGROVE - FRESHWATER
4 MANGROVE - POLYHALINE

FIGURE 2. MAJOR PLANT COVER ZONES BASED ON ELEVATION, DEPTH AND PROBABLE DURATION OF FLOODING.

period June through February. The approximate area of zone 2 is 374 ha.

Zone 3 is dominated by freshwater red mangroves of the "spider" type (Craighead 1971) with considerable acreage of open ponds along the northern edge of the zone. These ponds are often surrounded by tall *Eleocharis* or *Paspalum*. The clear water of these ponds, abundant periphyton and scant organic content of bottom muds suggests that, even here, dry down occurs often enough to permit oxidation of organics.

Marginal depth of water over the pond rims (30 cm) where *Eleocharis* and *Paspalum* flourish is about the same as the average depth in zone 1[1], but the depth of water in the open ponds probably averages 40 cm at normal rainy season maximum or about 10 cm lower that the confining banks which support tall *Eleocharis*, *Paspalum*, and red mangroves. The hydroperiod in this area probably averages 10 to 11 months.

Within zone 3 but a little farther south of these clear water, shallow ponds, one first encounters permanent water ponds surrounded by dense stands of trees dominated by red mangroves. The water is heavily stained with humic acids and *Chara* sp. becomes the dominant submerged macro-plant. *Ruppia maritima*, or widgeon-grass, is often found in shallow margins of these ponds. Typically, a berm surrounds these ponds and it appears that these ponds were once surrounded by buttonwood ridges on which cabbage palms grew as well. Peaty soil may exceed 60 cm in depth in these berms. The pond bottom sediments are not peat but fine sand mixed with a high percentage of fine organic flocculent material which makes these muds extremely sticky. Where *Chara* flourishes there invariably is a blue mud deposit indicating natural anerobiosis and high production of H_2S and methane. Zone 3 occupies 345 ha.

Seaward of the east-west running levee one enters the main mangrove forest association which can be best described as zone 4, polyhaline mangroves. Strictly speaking this zone encompasses the entire mangrove community between McIlvaine Bay and Unknown Bay. Primary interest, however, is focused upon those portions lying east of the existing airport runway (Figure 1). The majority of this community consists of a 119-ha semi-impounded forest dominated by black mangroves of small to medium height lying behind the crest of a low levee (dashed line between L and Q of Figure 1) topped by large, dead buttonwoods. From that levee the land slopes gradually seaward to Unknown Bay and its associated creeks.

The impoundment behind the low buttonwood levee had evidently experienced greater fresh water influence prior to major drainage diversions further north. The increased saline influence has favored black and white mangroves at the expense of buttonwoods. In spite of the reduced fresh water input this impounded area remains inundated for up to 10 months of the year, and its lowest spots are probably always flooded to between 10 and 20 cm by a combination of residual fresh and tidal waters.

ACKNOWLEDGEMENTS

I greatly appreciate the assistance and keen observations of Durbin C. Tabb and Gary L. Beardsley in preparing this report.

LITERATURE CITED

Cavinder, T.; Hicks, D.; Howard, H.; Koenig, M.; Murphy, P. A survey of physical, chemical and biological characteristics; Unit 30, Marco Island, Florida, August 1978 and March 1979. U.S. Environmental Protection Agency, Region IV; 1979.

Courtney, C. A limnological description of Lake Marco Shores-- a man-made, brackish water lake. A thesis submitted in partial fulfillment of the requirements for the Degree of Master of Science in Environmental and Urban Systems at Florida International University; 1979.

Craighead, F.C. The trees of South Florida. Coral Gables, FL: The University of Miami Press; 1971.

Reark, J.B. Ecological investigations in the Everglades. University of Miami, Department of Biology, First Annual Report. 1960; 25 p. (mimeo).

Reark, J.B. Ecological investigations in the Everglades. University of Miami,Department of Biology, Second Annual Report. 1961; 19 p. (mimeo)

Van Meter, N. Some quantitative and qualitative aspects of periphyton in the Everglades. Coral Gables, FL: University of Miami; 1965. Thesis.

MEROMIXIS IN A COASTAL ZONE EXCAVATION

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Applied Environmental Services
Marco Island, Florida

INTRODUCTION

Lake Marco Shores was created as a dredge and dragline excavation in 1972 when The Deltona Corporation developed the Marco Shores Golf Course and Airport (Figure 1). Much interest has been expressed in this lake because of its use as a prototype of additional proposed excavations.

Over the period 28 October 1976 to 21 June 1977, I conducted seven preliminary profiles of temperature, conductivity, salinity and dissolved oxygen in the lake. Observations indicated that Lake Marco Shores was developing a meromictic type of stability composed of three vertical strata: the mixolimnion, the chemocline, and the monimolimnion.

MATERIALS AND METHODS

Because each of the three layers was easily definable by in situ measurement, an intensive sampling program was employed from January to December 1978 to describe changes within these layers over an annual cycle. During that interval over 40 trips were made to each of two stations on the lake (Figure 2) to monitor the vertical distribution of the following routine parameters: Secchi depth, temperature, conductivity, salinity, and dissolved oxygen. On 20 January 1977 during an unprecedented cold spell (air temperature reached 2.2°C) a profile of temperature was made to a depth of 3.5 m in 0.3 m increments using a YSI Model 47 Scanning Telethermometer coupled to a YSI Model 80A Single Channel Laboratory Recorder. A series of twelve monthly chemical profiles were made. Nutrients were analyzed by standard methods (Strickland and Parsons 1972; USEPA 1974, 1975; Rand et al. 1976).

The bathymetry of the lake (Figure 2) was accomplished during the period 25-26 October 1976 using a Raytheon Model DE-719B Survey Fathometer. Continuous climatological data were collected at two sites (Marco Island and Rookery Bay) which bracketed the lake at distances of approximately 4.8 km. Additional rainfall data were collected on a weekly basis at two locations in the watershed of Lake Marco Shores and at two locations on the lake shore (Figure 1), using Taylor wedge type rain collectors mounted on staffs which also served as references to monitor weekly surface water levels. On each trip to the lake actual wave heights were measured against a fixed staff at the eastern end of the lake for comparison with maximum theoretical values. Five clusters of 4 well points each were installed around the lake to determine if ground water exhibited the same vertical structure as the lake.

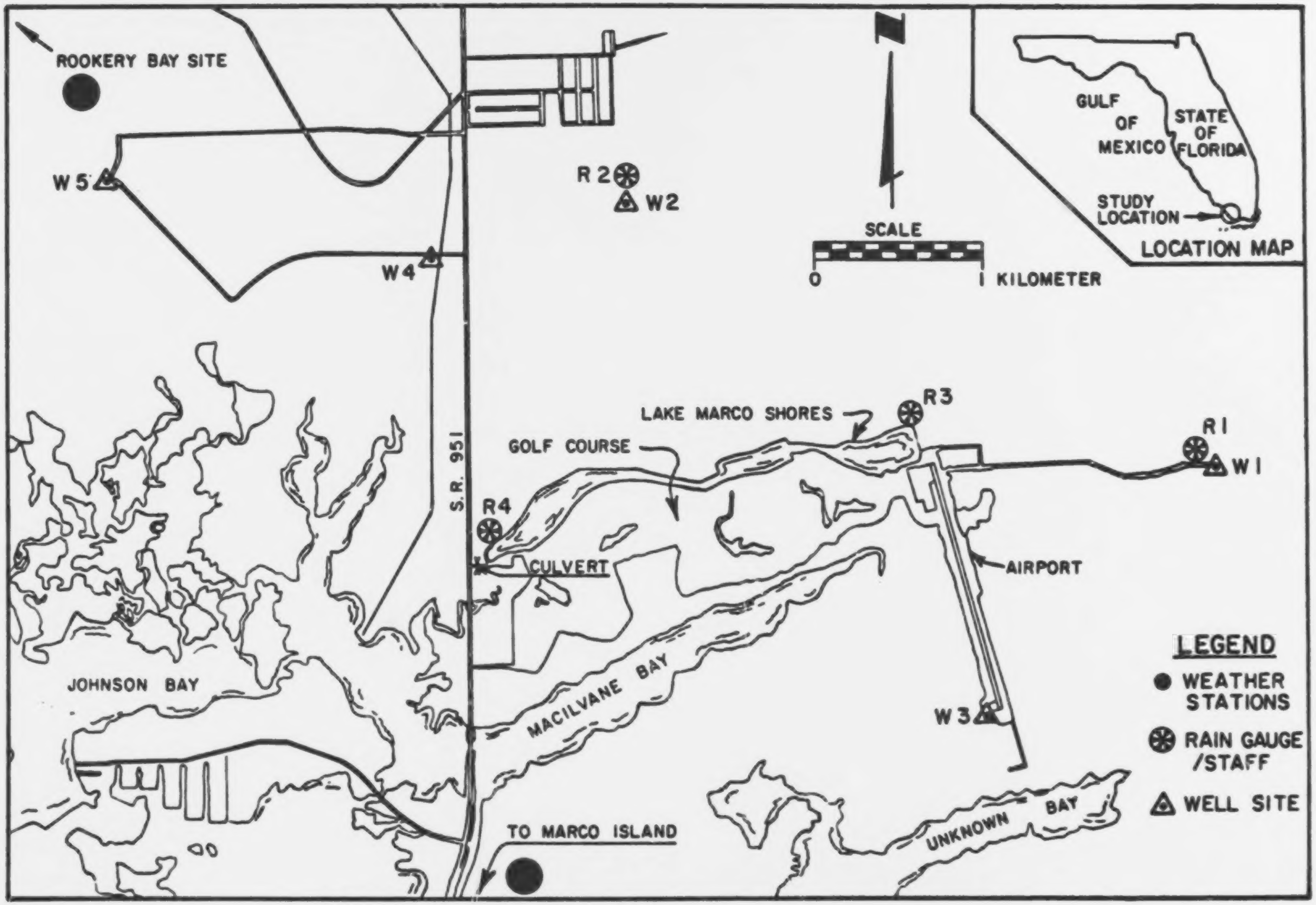
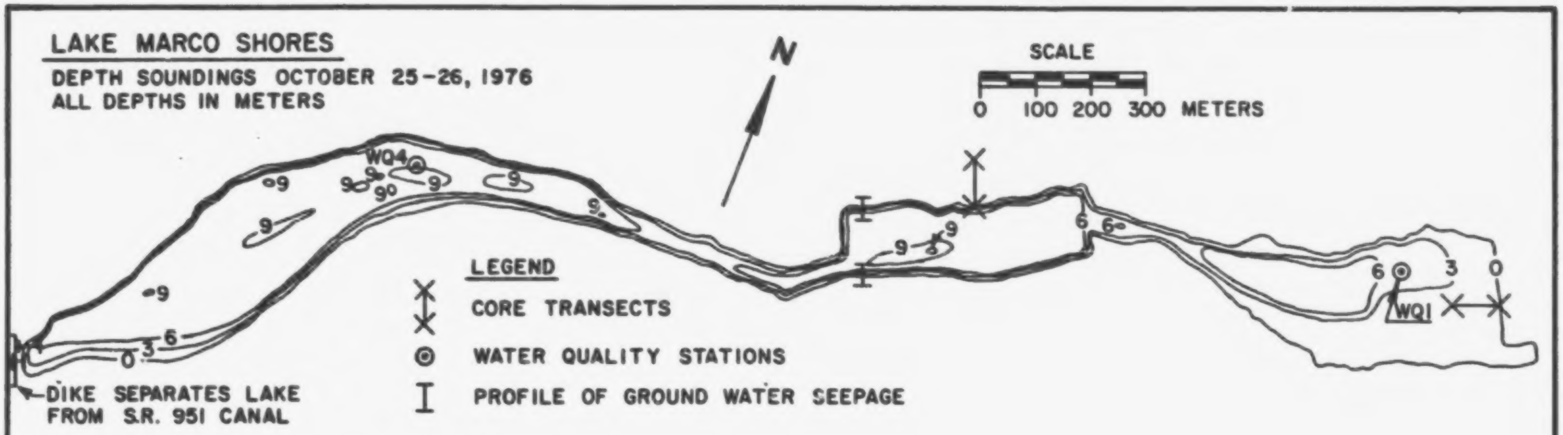

ROOKERY BAY SITE
W5
W4
R2
W2
SCALE
0
1 KILOMETER
GULF OF MEXICO
STATE OF FLORIDA
STUDY LOCATION
LOCATION MAP
LAKE MARCO SHORES
R3
R1
W1
GOLF COURSE
S.R. 951
R4
CULVERT
AIRPORT
JOHNSON BAY
MACILVANE BAY
W3
LEGEND
WEATHER STATIONS
RAIN GAUGE /STAFF
WELL SITE
TO MARCO ISLAND
UNKNOWN BAY

Figure 1. A site map showing the location of Lake Marco Shores.


LAKE MARCO SHORES
DEPTH SOUNDINGS OCTOBER 25-26, 1976
ALL DEPTHS IN METERS
N
SCALE
0 100 200 300 METERS
WQ4
9
6
3
0
WQ1
LEGEND
CORE TRANSECTS
WATER QUALITY STATIONS
PROFILE OF GROUND WATER SEEPAGE
DIKE SEPARATES LAKE FROM S.R. 951 CANAL

Parameters	Calculated* Value
Area (A)	34.83 ha.
Length (l)	3442.90 m
Breadth (b)	237.90 m
Maximum depth (Zm)	9.00 m
Mean depth (Zm)	5.60 m
Average Elevation of lake surface	0.46 m (NGVD)
Depth of crypto depression (Zc)	7.50 m
Volume (V)	1958089.60 m^3

*after Hutchinson (1975a)

Figure 2. A bathymetric map of Lake Marco Shores showing pertinent morphometric data.

RESULTS

Precipitation at the National Weather Service station in Fort Myers (1940-1970) indicated an annual average rainfall of 135 cm for the study area (Reynolds et al. 1979). When 1978 records at the two sites bracketing Lake Marco Shores are compared to these data, they indicate a below average rainfall (115 cm). Furthermore, the more coastal site has a net rainfall deficit when compared to the mainland site.

Theoretical maximum wave heights (0.3 m and 0.46 m) for the longest fetch distances (944 m and 881 m, respectively) were never approached during periods of maximum wind (60 km/h) at the lake. Observed wave heights only ranged from zero to 0.24 m for the forty observations. Increased wind speed was not correlated with increases in mixolimnionic salinity.

Water level hydrographs for each of the staffs in the lake and in the surrounding watershed are shown in Figure 3 along with mean rainfall records for all (4) of the wedge rain gages. Minimum water elevations occurred during the month of April as a result of the effects of the previous dry season while maximum water levels occurred in the August-September period at the end of the rainy season.

Well chemical data generally indicated that the same type of hypersaline water which occurred below the chemocline in the lake was typical of ground water in the area surrounding the lake. Salinities from the two deepest well points were always hypersaline. The surface aquifer on on the other hand was usually brackish. Ammonia-nitrogen was generally highest in samples from the deeper well points. Total phosphate and orthophosphates were always highest in samples from the deeper aquifer. Hydrogen sulfide and high color were most frequently observed in samples from Well No. 3 located nearest to tidal waters. All wells showed slightly acidic pHs (range 6.3-6.9).

Analysis of water elevations in wells revealed a general trend of decreasing ground water levels in the surface aquifer over the October-December period. This coincided with a drop in surface water levels in the impounded area.

Secchi disk transparencies (Figure 4) ranged over a small interval for the year (1.37 m to 2.44 m), and averaged 1.89 m (n=38; s.d.=0.31m) although there was a general trend toward decreased transparency during the April-September rainy season. Secchi depths never exceeded the depth of the bottom of the chemocline.

Temperature profiles in the lake for the periods January-June and July-December are presented in Figure 5. Each monthly value represents an average of from two to four "weekly" measurements. Lake Marco Shores was homiothermic below a depth of 4.0 m for the entire year with monimolimnionic waters only ranging from 25.0° to 26.5°C. This temperature interval coincided with the average maximum summer air temperatures.

Dissolved oxygen profiles (Figure 6) were remarkably uniform over the study period and showed a nearly saturated mixolimnion to a depth of 2.0 m. There was a rapid rate of oxygen decrease across the chemocline (2.0 m to 2.5 m) with no oxygen below the 3.7-m depth. This stability was evident throughout the coldest, windiest, and rainiest months (January, December, September, respectively).

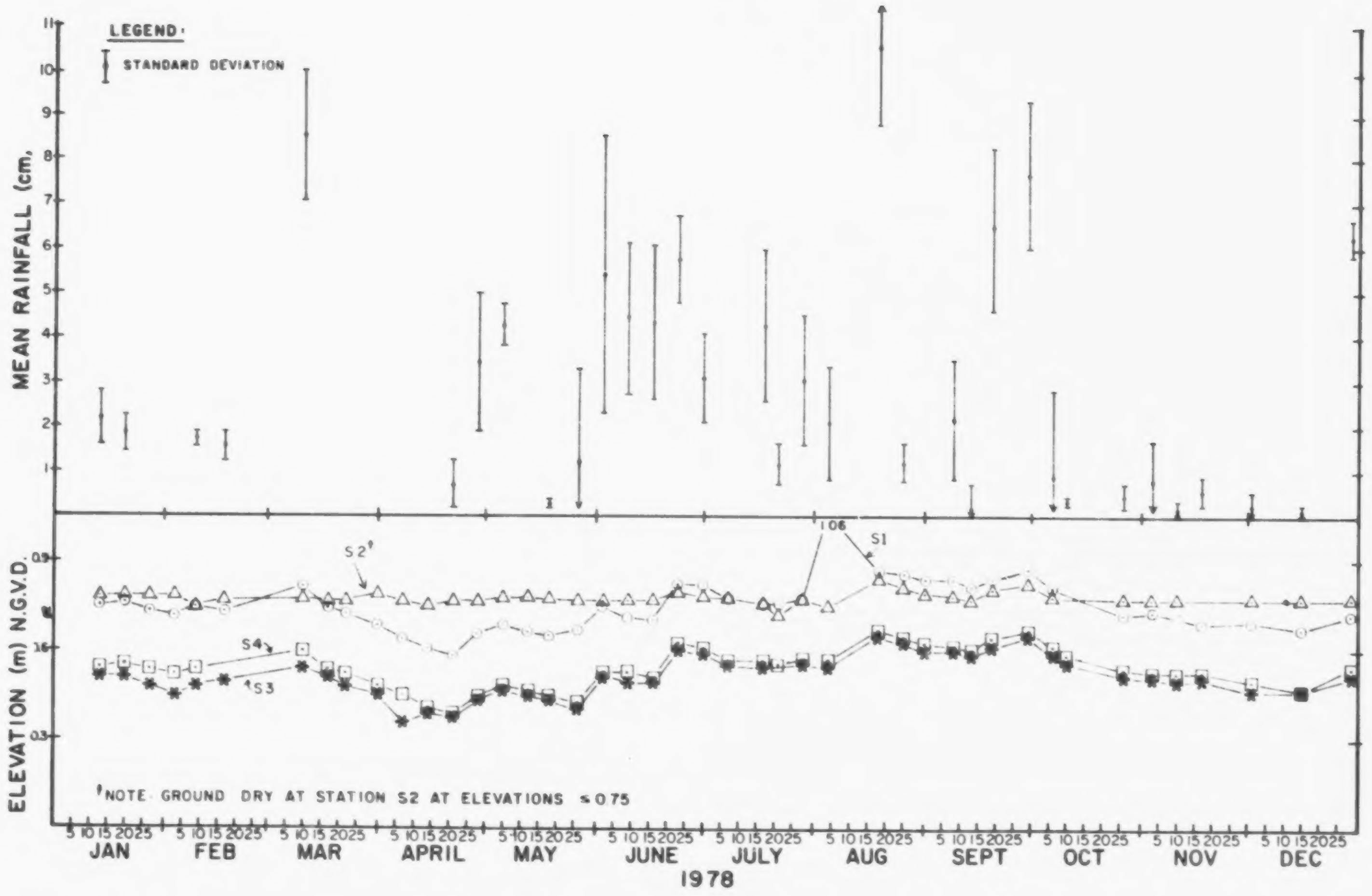


Figure 3. Water level hydrographs and rainfall records for the Lake Marco Shores basin.

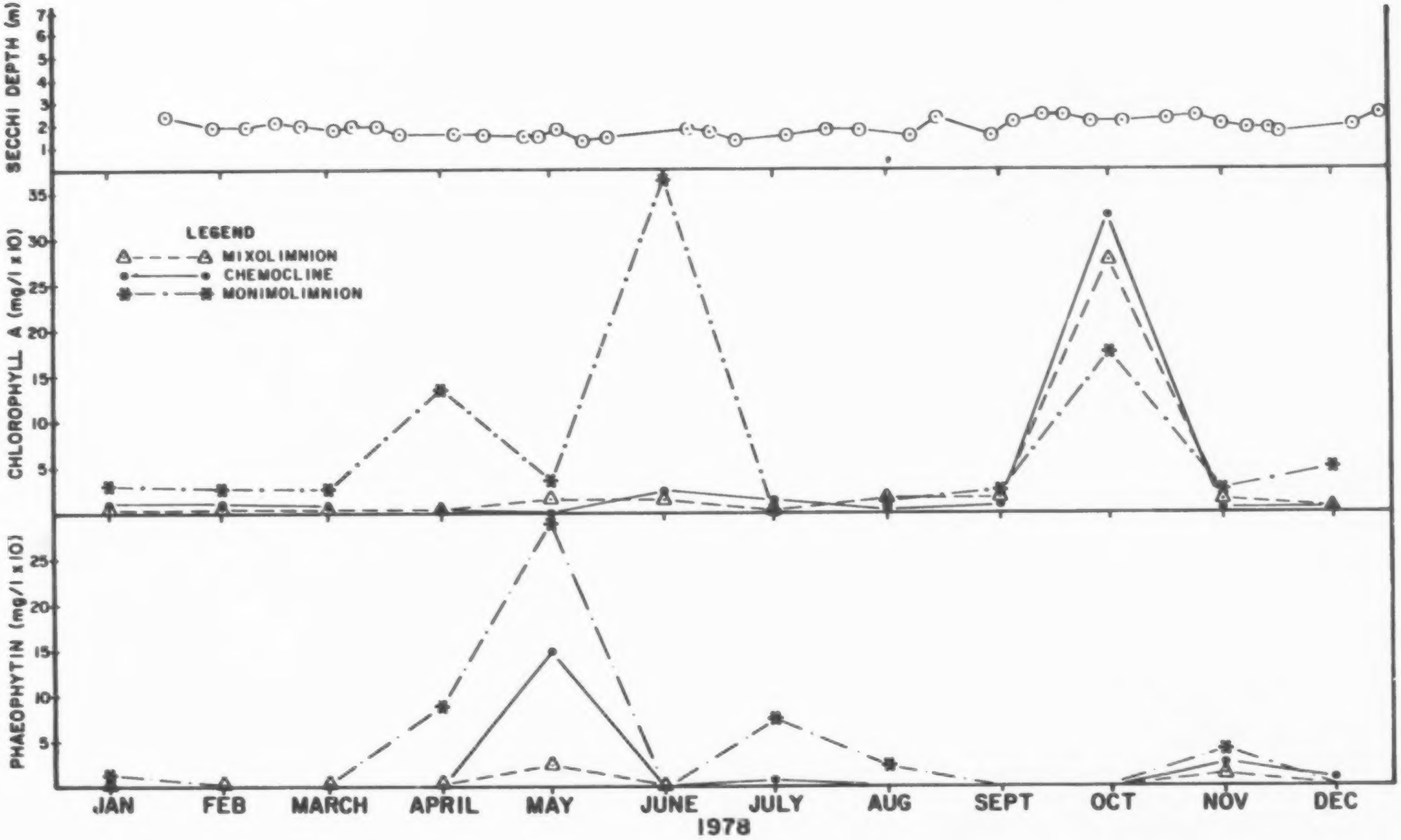


Figure 4. Chlorophyll, phaeophytin and secchi measurements at Lake Marco Shores for 1978.

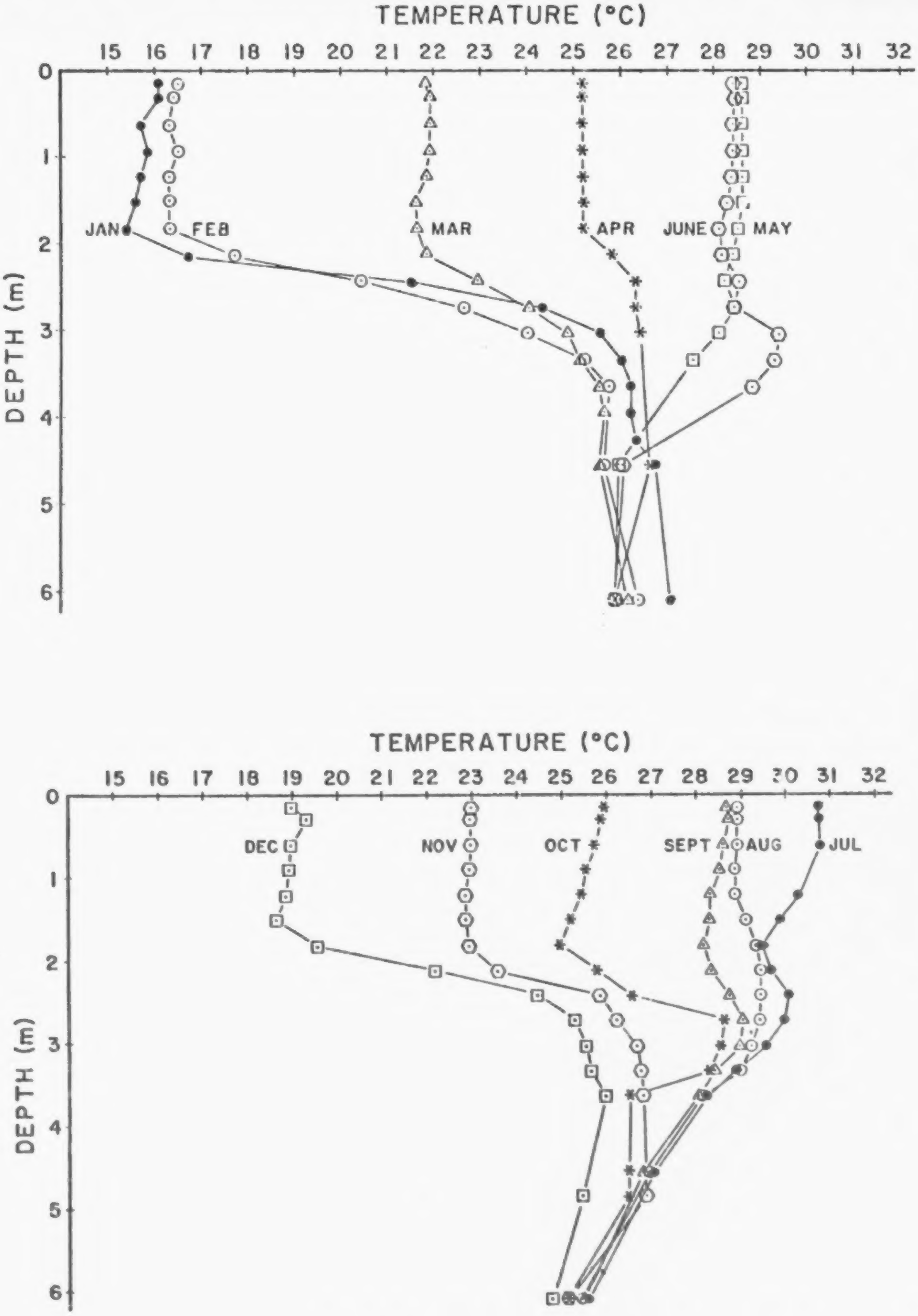


Figure 5. Temperature profiles at Lake Marco Shores for 1978.

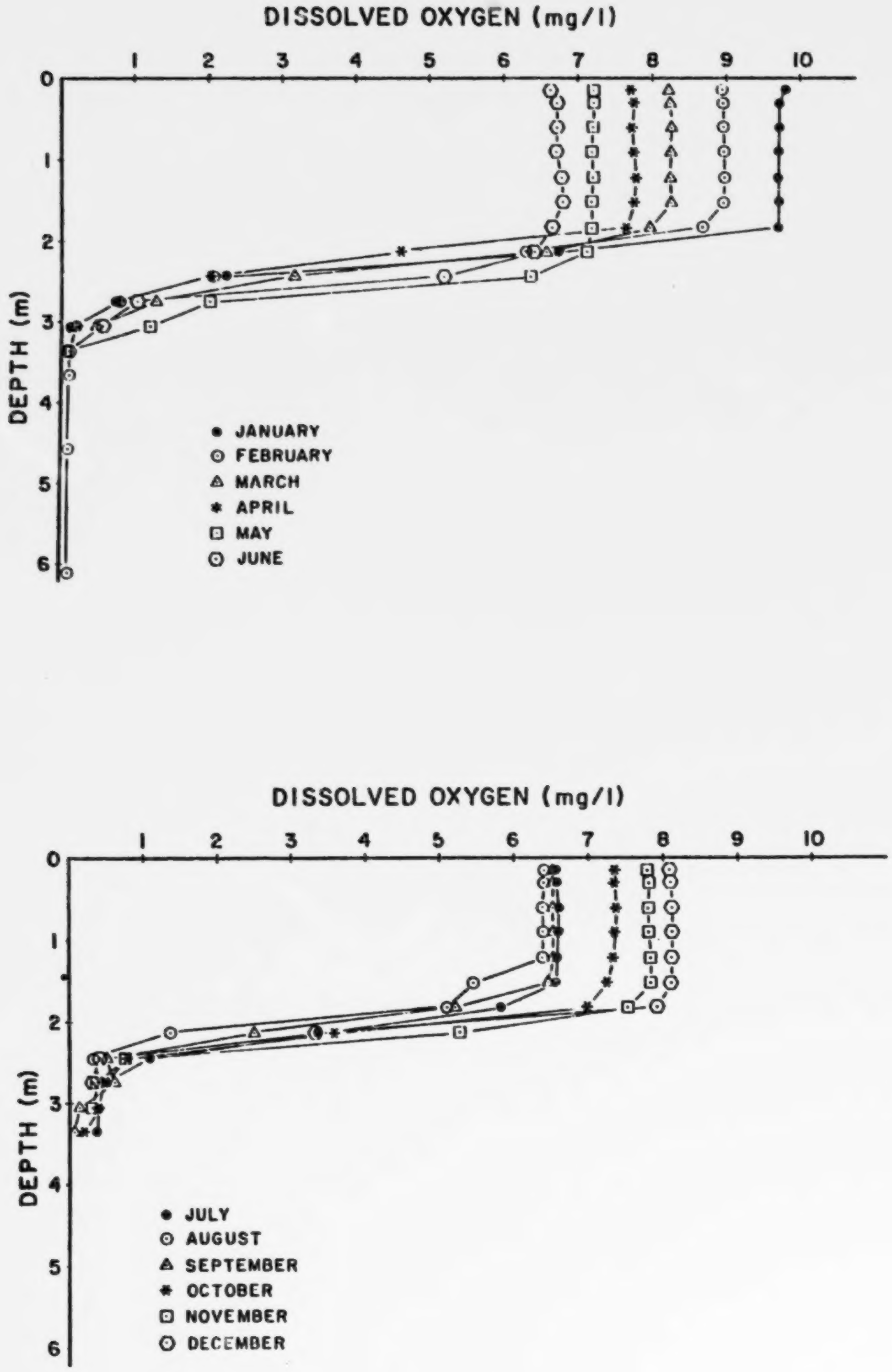


Figure 6. Dissolved oxygen profiles at Lake Marco Shores for 1978.

A hydrogen sulfide odor was always noticed whenever pumped samples from the monimolimnion were collected.

Total Kjedahl nitrogen (TKN) values (Figure 7) were low over the study period in both the mixolimnion and chemocline ($\overline{x}$ = 0.96 mg/l and $\overline{x}$ = 0.79 mg/l, respectively). Higher amounts of TKN were, however, always present in the monimolimnion ($\overline{x}$ = 3.13 mg/l). Ammonia-nitrogen concentrations in this layer ($\overline{x}$ = 0.69 mg/l) made up as much as 22 percent of the TKN concentration. Data from the monimolimnion also indicated that there may have been an association between rainfall and TKN levels in this layer.

Total organic carbon was sampled in profile on 13 March 1979, and values ranged from a low of 6 mg/l in the mixolimnion to a high of 13.5 mg/l at the bottom of the chemocline (3.0 m).

Salinity profiles in the lake indicated that a slight freshening of the mixolimnion occurred during the periods of January-March and July-August. Salinities in the mixolimnion ranged from a low of 1.44°/oo in September to a high of 7.3°/oo in December. On the average, salinities increased from 4°/oo to 40°/oo with an increase of depth from 2 m to 3 m. Stable hypersaline conditions prevailed throughout the year in the monimolimnion reaching an average of 43.0°/oo at the 6.1 m depth.

Total phosphorus (Figure 7) ranged from 0.001 mg/l to 0.9 mg/l with highest concentrations occurring in the monimolimnion. There was no seasonal trend evident for this nutrient although there was a peak in the October sample. Total phosphorus was also highest in the monimolimnion, with a trend toward higher concentrations in the rainy season (June - September) apparent.

Ammonia-nitrogen averaged 0.545 mg/l (s.d. = 0.481) over an annual cycle in the monimolimnion but was found in very low concentrations ($\overline{x}$ = 0.028 mg/l; s.d. = 0.035) in the mixolimnion and chemocline. Nitrate-nitrogen formed the second most abundant form of nitrogen but like ammonia, was found in greater concentrations with increasing depth (Mixolimnion $\overline{x}$ = 0.001 mg/l: chemocline $\overline{x}$ = 0.016 mg/l; and monimolimnion $\overline{x}$ = 0.018 mg/l). The same was true for NO_2-N which increased from an average of 0.001 mg/l in the mixolimnion to 0.008 mg/l in the monimolimnion.

DISCUSSION

In Lake Marco Shores the chemocline is formed at the depth determined by the relative rates of surface and ground water net inputs, the density difference between the mixolimnion and the monimolimnion, and the amount of energy available for mixing. Water is not retained above a critical elevation at Lake Marco Shores, and it is discharged as surface and ground water flow to the SR 951 Canal. Hence, the chemocline is not driven further downward as the rainy season progresses.

The vertical physical structure of Lake Marco Shores is similar to that of other meromictic lakes. Heat retention in the monimolimnion was observed by Anderson (1958) for Hot Lake, Washington, where the green house effect allowed heating of the monimolimnion to 50°C. He noted that this heat was retained through the winter. The relatively high specific heat capacity of such dense, saline lower layers has been found to be so effective at retaining heat that the construction of ponds of similar structure has received much recent theoretical and practical attention for use in space heating in cold climates (Rabl and Nielson 1975;

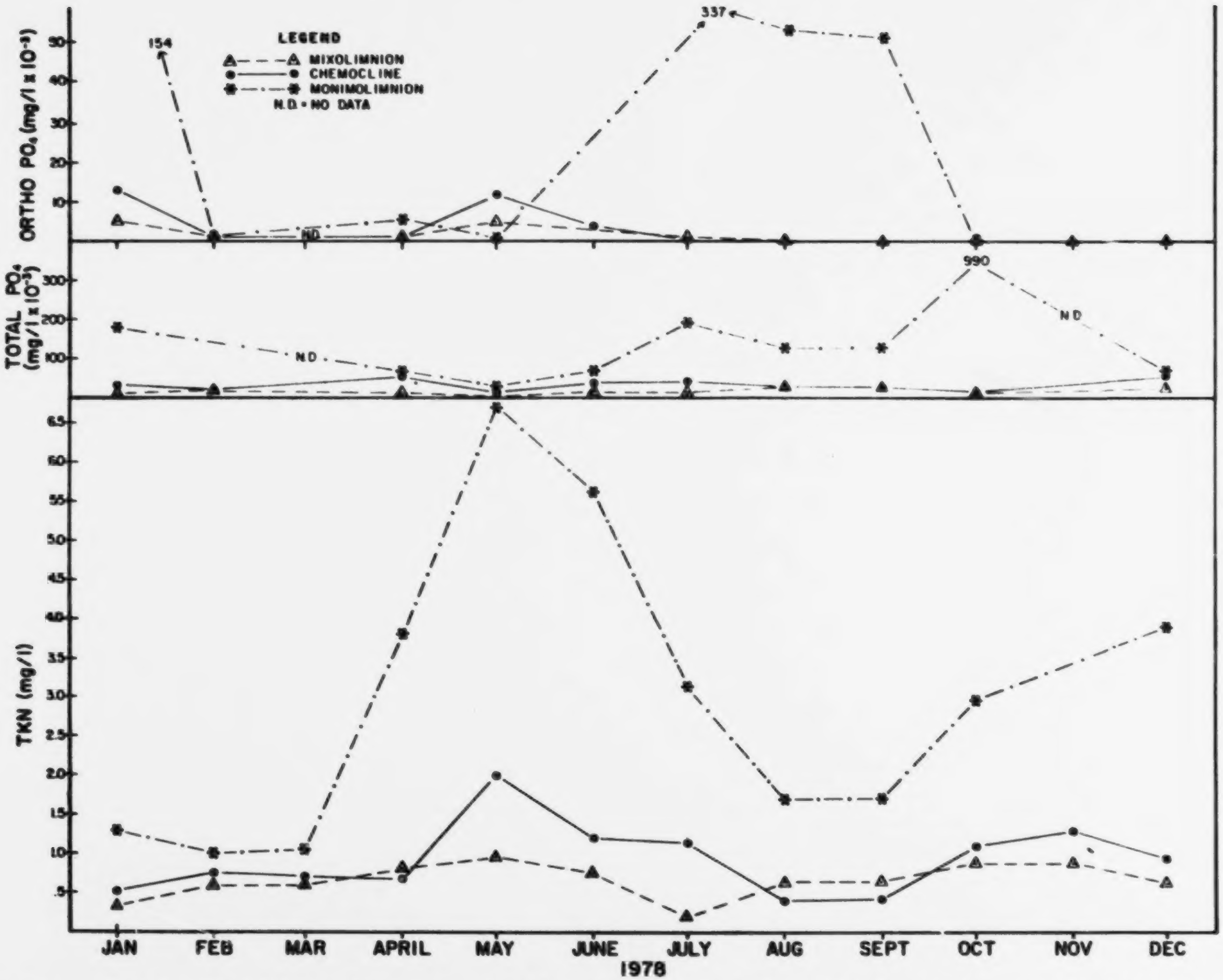


Figure 7. Total Kjeldahl nitrogen, total phosphate and orthophosphate levels at Lake Marco Shores for 1978.

Zangrando and Bryant 1978). The seasonal changes in temperature relative to salinity at Lake Marco Shores did not permit a turnover of the water column. The results of the 24-hour continuous profile of lake water temperatures during the 19-21 January 1977 cold spell are depicted in Figure 8. These data show that even when night air temperatures dropped to 2°C the only temperature effects in the water column were a 3°C decrease in surface water temperature and a slight compression of the thermocline.

During the times of minimal temperature difference between the mixolimnion and monimolimnion when cooling might have caused mixing, the salinity difference between the two layers was greatest. Furthermore, the thermocline that formed at the interface between the two layers during the remaining months was usually quite pronounced imparting a great degree of stability over an annual cycle. Below this thermocline, I found high suspended solids (<20 mg/l) and turbidity relative to the surface layer. These data may indicate an entrainment of suspended materials in the dense lower layer. Ritchie et al. (1978) have shown that when such thermoclines were present in four Mississippi reservoirs, a similar increase in suspended solids occurred in the top of the lower layer due to water level regulation in the reservoirs. X-ray diffraction analysis of deep lake sediments revealed that flocculation of some magnesium occurred in the lake. Riley and Chester (1971) note that the flocculation of clay minerals, such as magnesium calcite, occurs at fresh-salt water boundaries because water is drawn out of clay mineral settling units as the total ionic concentration of the surrounding solution increases. Such a boundary was present in the chemocline of the lake.

CONCLUSIONS

The results of this investigation suggest that coastal transition zone excavations in the area of the proposed development can become meromictic if they are sufficiently deep so as to intersect the intruding saline ground water and if they intersect seaward discharging surface aquifers. Lake Marco Shores is meromictic and extremely stable, permitting the lowest layer to accumulate nutrients. This same stability has prevented the concomitant expected stimulation of productivity and the surface layer of the lake has, in fact, become oligotrophic. Such excavated lakes, if properly designed and located in this unique area, may represent an interesting alternative for urban stormwater treatment in coastal areas.

LITERATURE CITED

Anderson, G. C. Some limnological features of a shallow saline meromictic lake. Limnology and Oceanography 3: 51-68; 1958.

Rabl, A.; Nielson, C. E. Solar ponds for space heating. Solar Energy 17112; 1975.

Rand, M. C.; Greenberg, A. E.; Taras, M. J., editors. Standard methods for the examination of water and wastewater. Washington, DC: American Public Health Assoc., 1976; 1193 p.

Reynolds, Smith and Hills. Big Cypress Basin excavation study. Basin Program No. 2502. Reynolds, Smith and Hills Environmental Science and Engineering, Inc. Report submitted to: Big Cypress Basin Board, South Florida Water Management District, January 1977. 1979; 1-1 to 6-23; 1979.

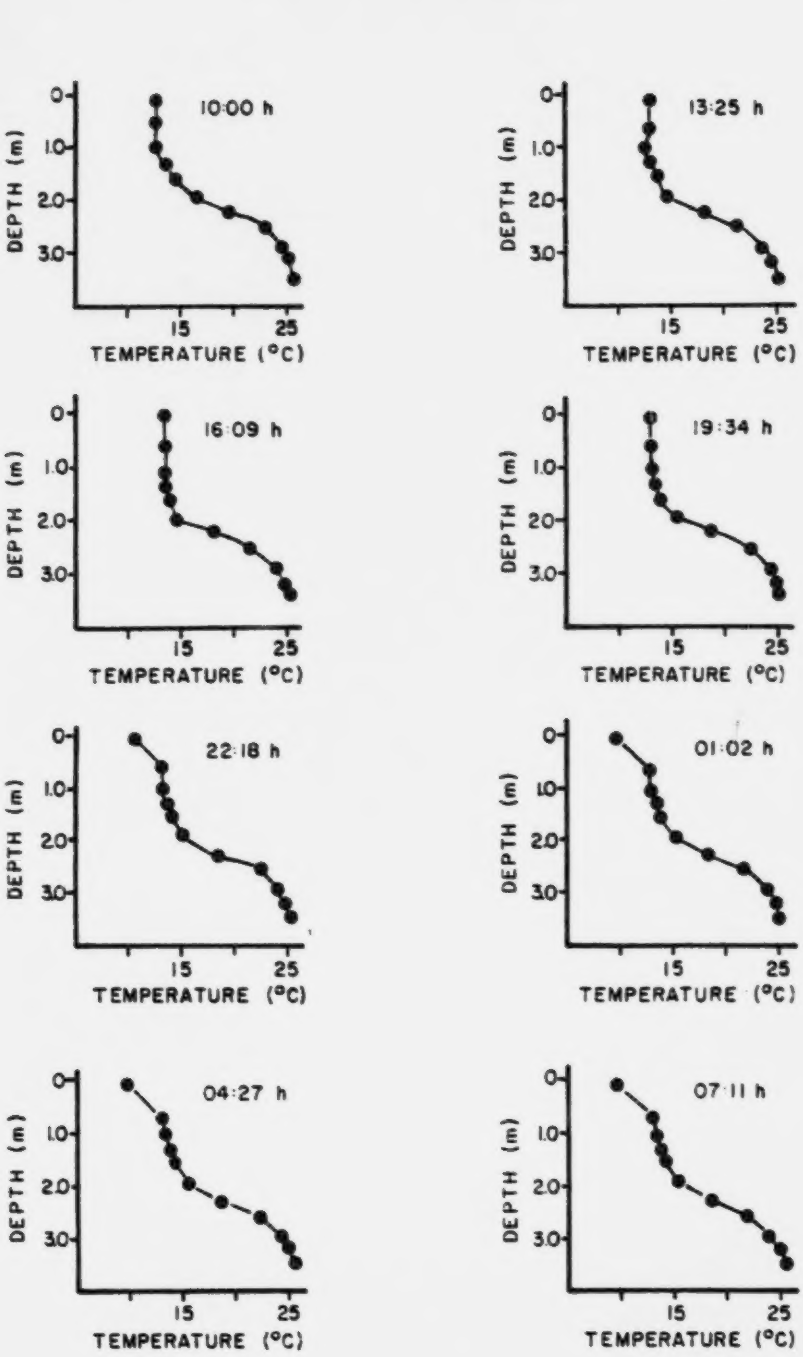


Figure 8. Results of a 24-hour continuous profile of Lake Marco Shores water temperatures for the 19-21 January 1977 cold spell.

Riley, J.P.; Chester, R. Introduction to marine chemistry. New York: Academic Press; 1971

Ritchie, J. C.; McHenry, J. R.; Schiebe, F.R. The vertical distribution of suspended sediments in reservoirs. Water Pollut. Control. Fed. 734-738; 1978.

Strickland, J.D.H.; Parsons, T. R. A practical handbook of seawater analysis. Ottowa, Canada: Fisheries Research Board of Canada. Bull. 167 (2nd Edition); 1972; 310 p.

Sverdrup, H.V.; Johnson, M.W.; Fleming, R. H. The oceans. New York: Prentice Hall; 1942. 1087p.

USEPA. Methods for chemical analysis of water and wastes, 1974. Cincinnati, OH: USEPA Environmental Monitoring and Support Laboratory; 1974.

USEPA. Chemical analysis for water pollutants. Training manual. Cincinnati, Ohio: USEPA Office of Water Program Operations. 11-241; 1975.

Zangrando, F.; Bryant, H. C. A salt gradient solar pond. Solar Age 2136; 1978.

SURFACE WATER FLOW FROM A SOUTH FLORIDA WETLAND AREA

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INTRODUCTION

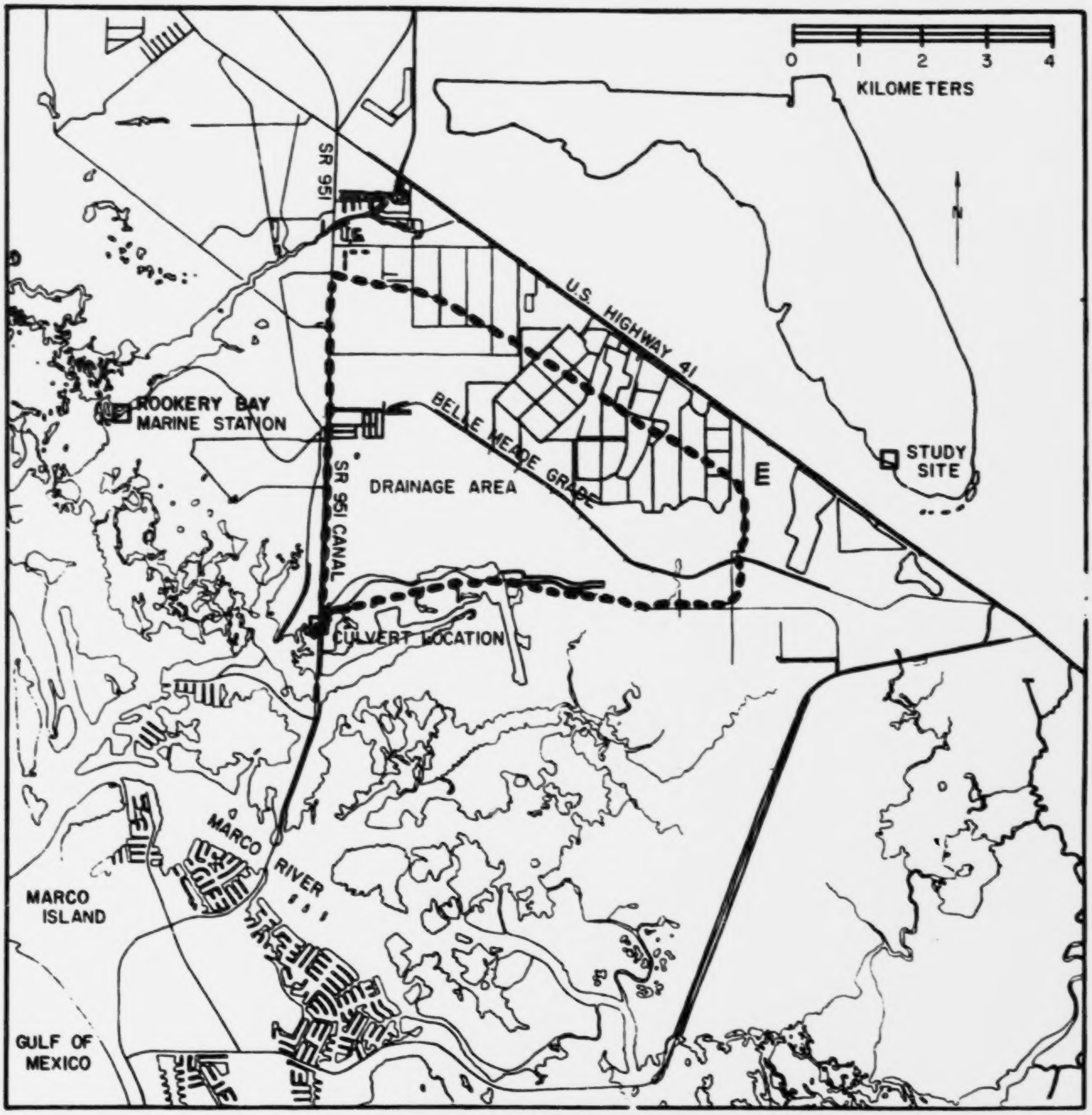
The study site is a wetland region of approximately 5,300 acres near Marco Island in southwest Florida (Figure 1). Vegetation ranges from impounded mangrove wetlands on the south, to freshwater marsh, to pine, palmetto, and farm areas on the north. Elevations grade from about 0.6 m above mean sea level along the southern boundary to 1.5 m above sea level on the north.

The drainage area, established from aerial photographs and field inspection, is defined by a drainage divide on the north, north-south roads on the east and west, and on the south by east-west roads, a golf course, an airport, and a man-made lake. The basin has been divided into two separate hydrologic units of approximately equal area by construction of the Belle Mead Grade. The region to the north is composed of roughly equal proportions of farmland and pine and palmetto forest receiving little or no tidal influence. To the south is an area of about 400 acres of pine and palmetto forest, 700 acres of freshwater marsh and 1,000 acres of mostly white and red mangroves. On an additional 400 acres along the southern perimeter is a man-made lake, golf course, and airport (Tabb et al. 1977).

Surface water is exported westward from the regions both north and south of the Belle Meade Grade via sheet flow until it reaches the State Road 951 Canal which conveys it southward. On the southwest corner of the drainage basin is a road crossing the canal. Water is conveyed past this obstruction by three 0.91-meter diameter, 16.8-meter long culverts. Flow direction through the culverts alternates with the tide except during the rainy season when flow is exclusively out of the region for extensive periods of time. As will be discussed in the next section, the culverts are a convenient device for quantifying the flow in and out of the wetland area.

EXPERIMENTAL METHODS

Water discharges through the culverts were determined by measuring water levels at the north and south ends of the culverts with two Fisher Porter tide gauges. Water levels were recorded on paper tape every 6 minutes for an 18-month period beginning in May 1977.


0
1
2
3
4
KILOMETERS
N
SR 951
U.S. HIGHWAY 41
ROOKERY BAY
MARINE STATION
BELLE MEADE GRADE
STUDY
SITE
E
DRAINAGE AREA
SR 951 CANAL
CULVERT LOCATION
MARCO
RIVER
MARCO
ISLAND
GULF OF
MEXICO

------- Drainage area contributing surface water runoff to culverts

FIG. 1 - STUDY SITE

To establish a relationship between head difference across the pipes and water discharge through the pipes, simultaneous water level and discharge measurements were conducted on May 30, 1977; June 3, 6, and 21, 1977; and April 5, 1978. Water velocity in the canal immediately south of the culverts was determined by timing drogue transits over a 15-m range. Concurrently, water elevations were noted at tide staffs located at the north and south ends of the culverts. The water elevation at the south staff allowed for determining the cross-sectional area of the open channel flow and therefore for the computation of discharge from velocity measurements.

Using Bernoulli's Equation with Manning's friction formulation and expressing quantities in metric units, the head loss across a pipe can be expressed as:

$$h = h_1 - h_2 = \frac{V_P^2}{2g} \left(k_v + k_e + \frac{2\,gn^2L}{R^{4/3}}\right) - \frac{V_1^2}{2g} + \frac{V_2^2}{2g} \qquad (1)$$

where h_1 and h_2 are the water elevations at the respective ends of the pipe, V_P is the average water velocity through the pipe, g is gravity acceleration, k_v and k_e are the entrance and exit loss coefficients, respectively, n is Manning's friction coefficient, L is pipe length, and V_1 and V_2 are the water velocities in the open channel at the respective pipe ends. Letting A_1 and A_2 be the respective open channel flow cross-sectional areas at the pipe ends and A_P the cross-sectional area of an individual pipe we may express the discharge Q as

$$Q = A_1 V_1 = A_2 V_2 = 3\,A_P V_P \qquad (2)$$

Eliminating V_1, V_2, and V_P in Eqs. 1 and 2 yields

$$h = \left(\frac{k_v + k_e + 2\,gn^2L/R^{4/3}}{18\,gA_P^2} - \frac{1}{2gA_1^2} + \frac{1}{2gA_2^2}\right) Q^2 \qquad (3)$$

or $Q = K \quad h$

where K represents the quantity in Eq. 3 to the -1/2 power.

For the range of observed values of A_1 and A_2, terms 2 and 3 of Eq. 3 are negligible. The factor K in Eq. 4 then depends only on term 1 of Eq. 3. Its value was determined experimentally using 34 field measurements of water velocity and tidal elevation differences across the culverts. Values of discharges determined from velocity measurements were plotted on log-log paper versus observations of h (Figure 2). At least squares fit of a line of slope 2 drawn thorugh the 34 data points yielded a value of K of 2.56 $m^{5/2}$/sec with a corresponding standard deviation of 0.16 m^3/sec and correlation coefficient r = 0.9.

Figure 3 shows a comparison of discharges for 6 experiments computed from velocity measurements and from Eq. 4. Although individual discharges computed from Eq. 4 do

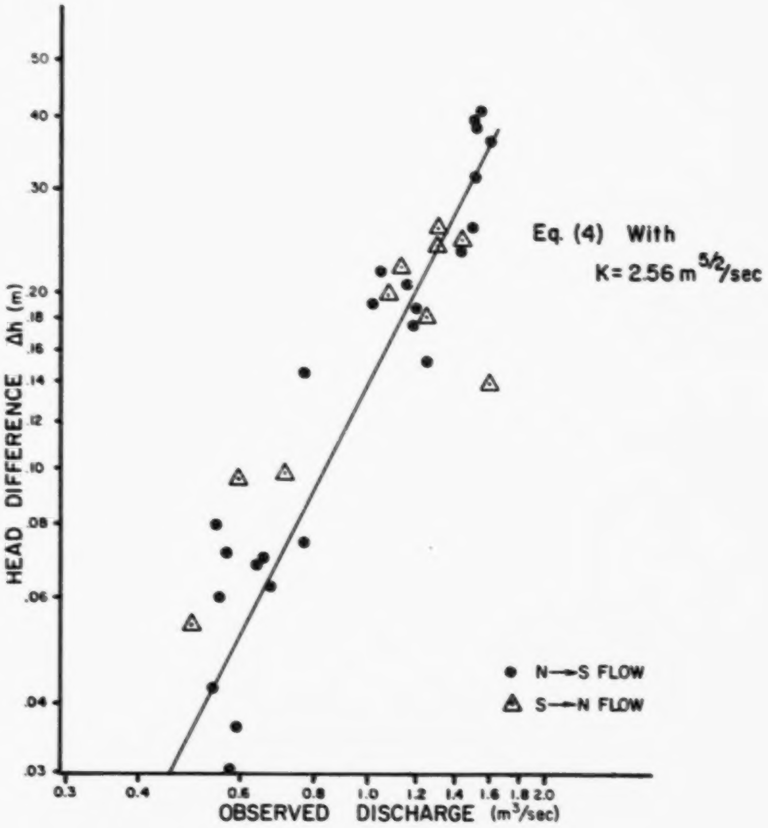
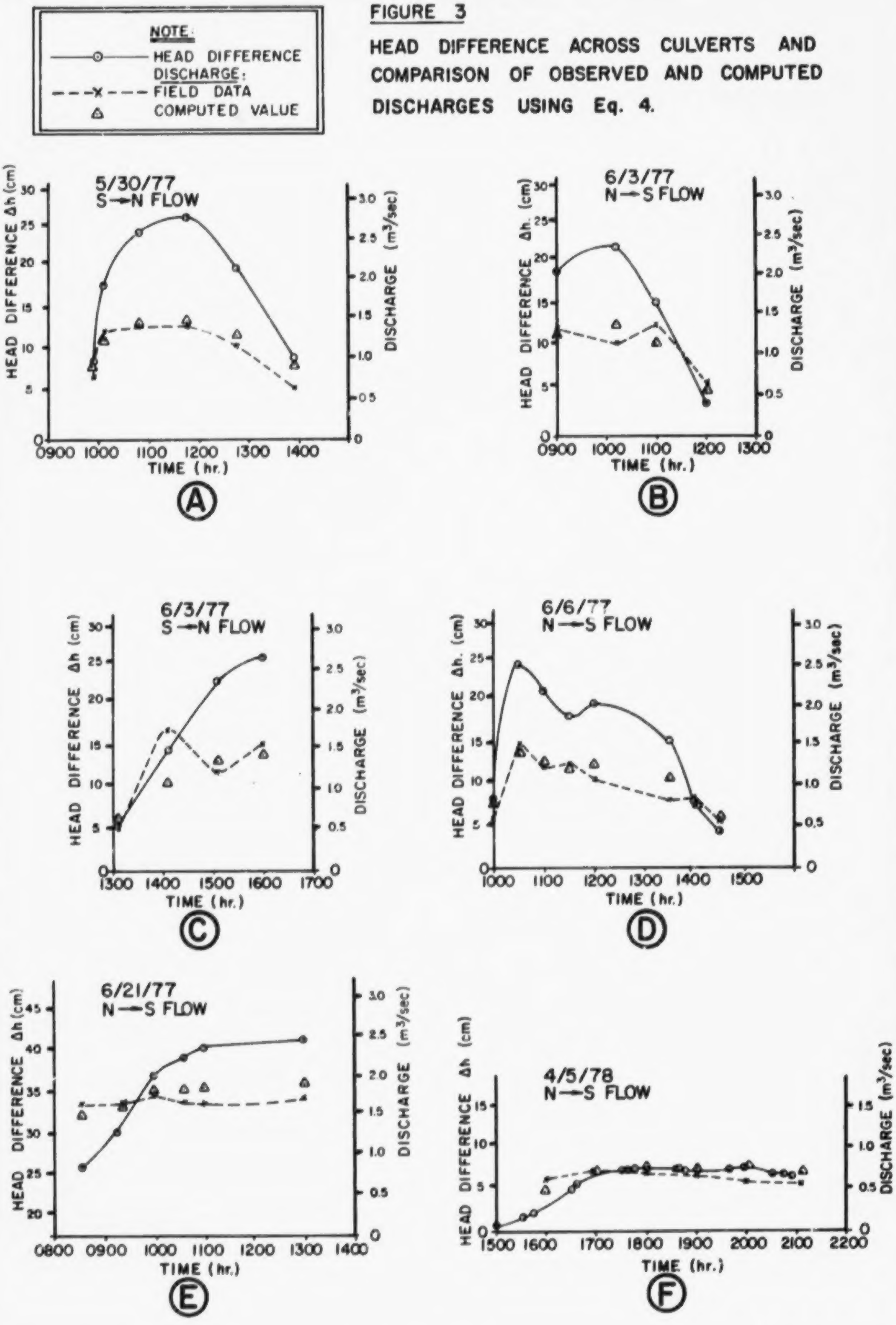


FIGURE 2

RELATION BETWEEN HEAD DIFFERENCE AND WATER DISCHARGE

FIGURE 3

HEAD DIFFERENCE ACROSS CULVERTS AND COMPARISON OF OBSERVED AND COMPUTED DISCHARGES USING Eq. 4.



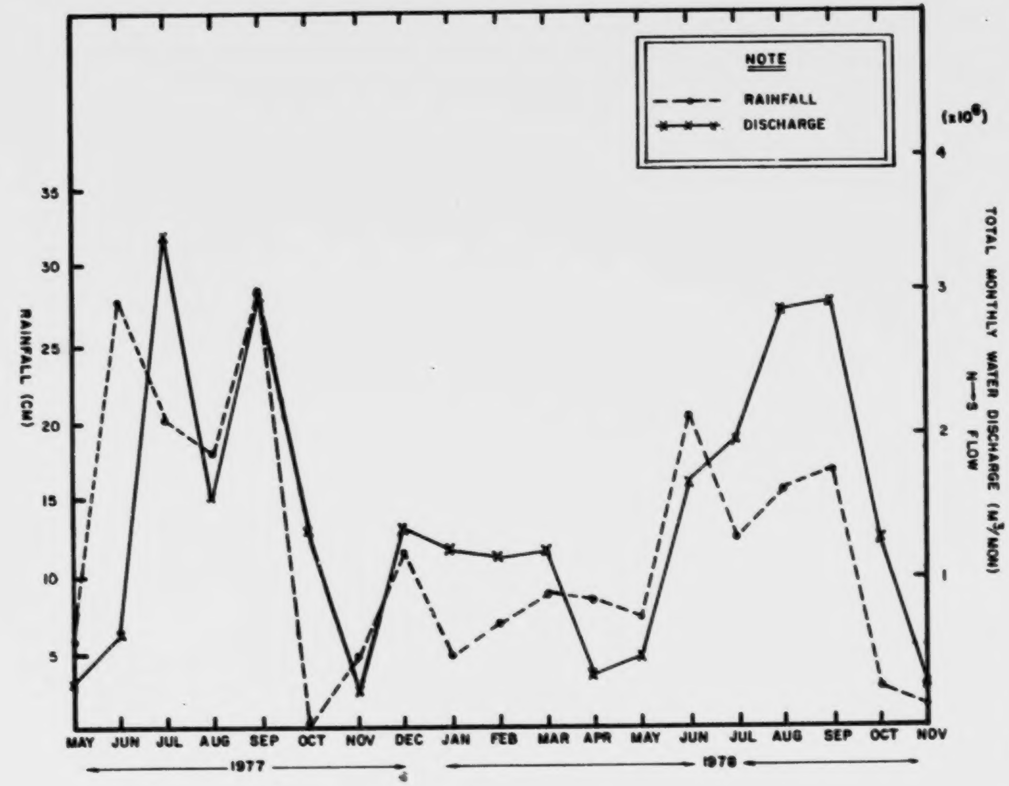
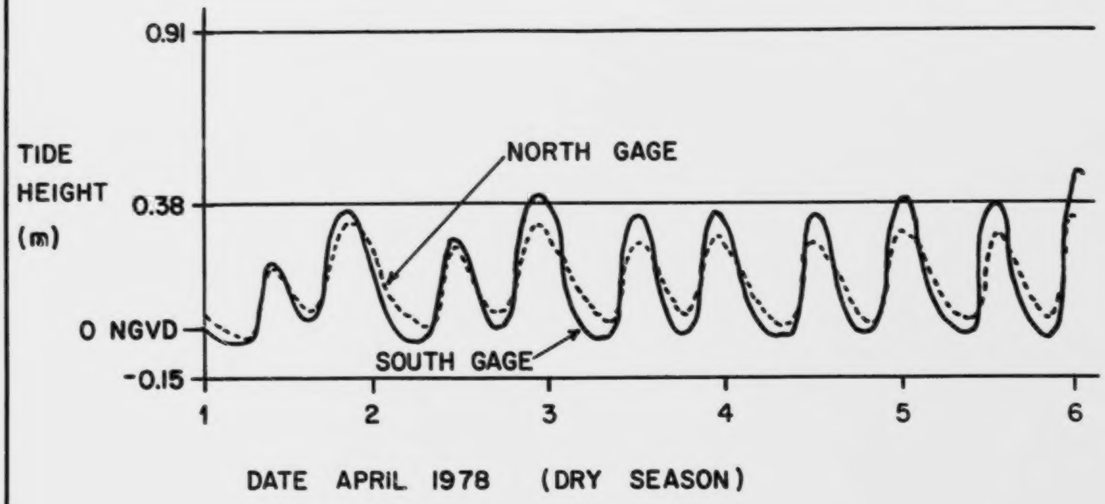


Fig. 4

Monthly rainfall at the Rookery Bay Marine Station and water discharge through culverts.



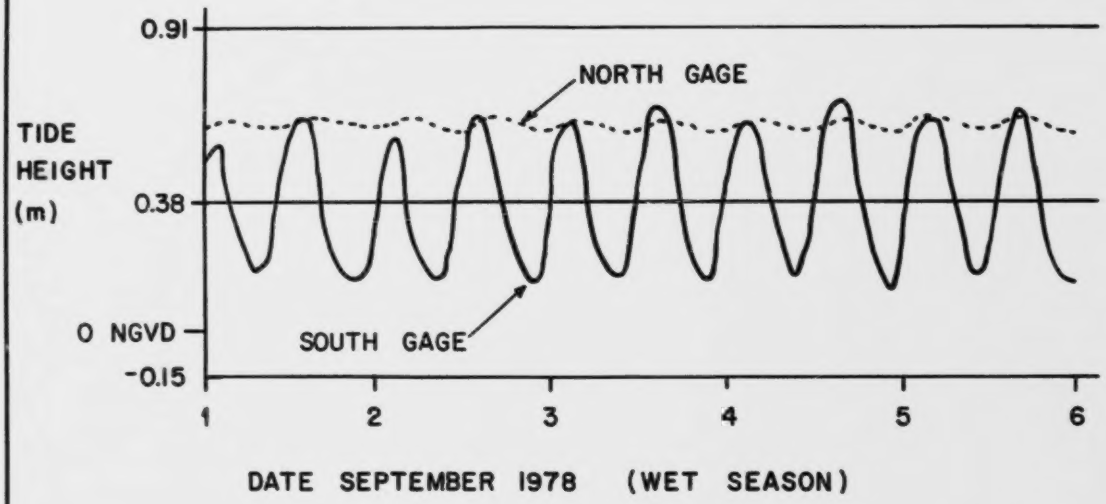


FIGURE 5

WET SEASON VS DRY SEASON MEASURED WATER LEVELS AT NORTH AND SOUTH ENDS OF CULVERTS not always agree with field measurements (for example Figures 3B and C), it is apparent that averages of observed and computed discharges taken over several points are in good agreement. A statistical analysis revealed that when averaging over a month the discharges computed from the 6-min tide records yields a maximum probable error of 0.075 m^3/sec at the 90 percent confidence level (Daddio and van de Kreeke 1979).

RESULTS

Figure 4 is a plot of the monthly rainfall recorded at the Rookery Bay Marine Station and the net monthly water discharge through the culverts computed using Eq. 4. The net water discharge is exclusively toward the south for the entire recording period. The discharge hydrograph shows a definite seasonal trend with the largest discharges occurring during the wet season (here defined as June through September). The maximum monthly discharge for one year beginning June 1977 is 3.51 x 10^6 m^3/month in July 1977. The dry season discharges are still substantial and on the order of 10^6 m^3/month with a minimum of 0.27 x 10^6 m^3/ month during the month of November 1977. For comparison the subsurface run-off is estimated at only 10^4 m^3/month based on figures presented by Amy (1980).

It is noteworthy that although water flowing through the culverts experiences tidal reversals for most of the year relatively few reversals occur through the wet season months. This is exemplified by measured water levels at the north and southside of the culverts during April (dry season), and September (wet season); see Figure 5. During September the water levels on the northside are practically always higher than the levels on the southside leading to unidirectional flow. During April the head difference changes sign. Mean water levels during September are about 0.20 m higher than during April.

The total rainfall for the 1-year period beginning June 1977 is 144 cm or 3.11 x 10^7 m^3 for the drainage basin of which 1.66 x 10^7 m^3 was discharged through the culverts. This yields a run-off ratio of 0.53 for the drainage basin. Assuming no net water storage over a period of a year, the remaining 47 percent of rainfall is lost largely by evapotranspiration. This percentage is considerably lower than the 76.2 percent evapotranspiration reported for the Big Cypress Swamp (Carter et al. 1973). This may be a result of accelerated runoff associated with channelization in this study area. Also, there exists a possibility that the freshwater lens on the golf course (Amy 1980) forces ground water derived from areas north of the drainage basin to surface and become part of the surface runoff.

CONCLUSIONS

Water export is determined with a semi-empirical relationship between discharge and water elevation differences across culverts which convey surface run-off out of the study area. Monthly water export ranges from 0.27 x 10^6 m^3/ month for November 1977 to 3.51 x 10^6 m^3/month for July 1977. The total flow for a one-year period is 1.66 x 10^7 m^3 representing 53 percent of the rainfall.

REFERENCES

Amy, V.P. The ground-water flow system in the vicinity of Marco Island, Fla. Cross, R.; Williams, D., eds., Proceedings of the National Symposium on Freshwater Inflow to Estuaries. San Antonio, Texas, September 9-11, 1980. Washington, DC: U.S. Fish and Wildlife Service, Office of Biological Services; 1981. FWS/OBS-81/04.

Carter, M. et al. Ecosystem analysis of the Big Cypress Swamp and estuaries. U. S. Environmental Protection Agency, Region IV; 1973.

Daddio, E.; van de Kreeke, J. Flux of dissolved organic carbon from a wetland area near Marco Island, Fla. Miami, FL: University of Miami; 1979. Rosenstiel School of Marine and Atmospheric Science Tech. Rep. TR 79-2.

Tabb, D.; Heald, E.; Beardsley, G. Natural resource assessment of Marco Island Mainland properties tract. Report to Deltona Corp., Miami, FL; 1977. Unpubl. ms.

WATER BUDGET AND PROJECTED WATER QUALITY IN PROPOSED MAN-MADE LAKES NEAR ESTUARIES IN THE MARCO ISLAND AREA, FLORIDA

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INTRODUCTION

The proposed Marco Island development plan calls for the excavation of a large group of interconnected lakes in two areas known as Units 24 and 30 near Marco Island, Florida. The area has been described in detail elsewhere in this series.

The land uses and lake areas are tabulated in Table 1 for Units 24 and 30. The latter is considerably larger both in total area and lake area. Existing Lake Marco Shores (see paper by Courtney) also will be incorporated into the lakes of Unit 30.

The quality of the proposed lakes is of considerable importance, both to the riparian owners and to the nearby estuarine areas that will receive surface discharges. Although the areas will be surrounded by berms sufficient to contain the 100-year storm volume, some net runoff will leave via spreader ditches and enter the mangrove and marsh areas. Hence, an a priori assessment of lake water quality was desired to evaluate the potential for problems within and downstream of the lakes. This paper describes the techniques used for the assessment.

Although the potential exists for a variety of pollutants to enter the lakes, only a few are critical to the lake evaluation. In particular, the nutrients, total nitrogen (T-N) and total phosphorus (T-P) are important to the long term potential for eutrophication and are examined in detail. Such common parameters as dissolved oxygen will not be a problem on the basis of data from existing Lake Marco Shores and experience with similar lakes elsewhere. Moreover, the scope of the parent investigation did not require a comprehensive evaluation of all water quality parameters. Hence, T-N and T-P are emphasized in this paper.

A complication is the fact that the deep lakes will be stratified due to the influx of hypersaline ground water below a depth of roughly 6.5 ft (2.0 m). Based on samples from existing Lake Marco Shores, water in the lower layer (monimolimnion) will likely be of poor quality, with high concentrations of nutrients. The fresh upper layer (mixolimnion), on the other hand, should be of much better quality; the point of this investigation is to determine how much better. The lakes will be meromictic, that is, permanently

Table 1. Land use categories.

	Unit	24	Unit	30
	(ac)	(%)	(ac)	(%)
Residential (Including schools, churches, parks, golf courses)	234.7	44	1147.77	40
Commercial	19.2	4	115.26	4
Roads & Right of Way	72.6	14	491.74	17
Multi-Family Residential	121.9	23	423.57	15
TOTAL LAND AREA	448.4	85	2178.34	76
Lakes				
Major Lake-Deep Area	60.20		361.64	
Major Lake-Shallow Area	19.76		342.55	
TOTAL LAKE AREA	79.96	15	704.19	24
TOTAL AREA	528.36	100	2883.53	100

NOTE: 1 ac x 0.405 = ha.

Table 2. Lake water budget evaluation.

		Unit 24 (in/yr)	Unit 30 (in/yr)
Inflow			
Precipitation		50.0	50.0
Surface Runoff		30.8	17.2
Interflow		39.2	21.9
Groundwater		41.2	14.0
	Inflows	161.2	103.1
Outflows			
Groundwater		41.2	14.0
Evaporation		44.4	44.4
Surface Outflow		75.6	44.7
	Outflows	161.2	013.1

(Note : Inches x 25.4 = mm)

stratified. Density differences are so great across the chemocline that the possibility of overturn is nil. Hence, the lower layer will influence the upper only by vertical diffusion.

LAKE WATER BUDGET

The lakes receive water from surface runoff from the various land uses; from interflow, (i.e., water that infiltrates to the shallow water table, forms a ground water mound, and thence moves laterally to the nearby lakes) from regional ground water flow in the shallow fresh water layer, and from direct rainfall. Water is lost by surface runoff, ground water outflows and evaporation. If the change in storage is zero on an average annual basis, then inflows equal outflows, and the water budget equation may be evaluated for each term.

Annual precipitation in the area is about 50 inches (1,270 mm). Surface runoff and interflow were evaluated utilizing a land surface evapotranspiration rate for the region of 75 percent of annual rainfall (Figure 1). Groundwater movement was determined by analysis of regional potentiometric contours (see paper by Amy in this proceedings). Lake evaporation was taken as 70 percent of pan, and surface outflows were deduced by subtraction, knowing all other terms. The derived water budget is shown in Table 2 in which units are inches over the lake surface area.

Assuming the depth of the freshwater layer in the lakes will be 6.5 ft (2 m) (Figure 2) residence times for these layers may be computed by dividing the volume above this depth by the sum of inflows (or outflows) in Table 2 expressed as a volumetric flow rate, yielding values of 0.42 and 0.65 years for Units 24 and 30 respectively. These values influence lake water quality.

LAKE NUTRIENT LOADINGS

The primary task is to develop loadings for TN and TP that coincide with the various pathways of the water budget inflows to the lake, plus possible diffusion from the lower layer. The latter was calculated on the basis of gradients measured across the chemocline in existing Lake Marco Shores. Concentrations in ground water and rainfall were measured. Loadings for urban stormwater were needed to evaluate this contribution to surface runoff and interflow.

Fortunately, Broward and Dade Counties (near Fort Lauderdale and Miami) in southeast Florida were the sites of four intensive urban runoff monitoring programs by the U.S. Geological Survey (USGS) in the mid 1970's (Mattraw and Sherwood 1977; Mattraw and Miller 1978; Hardee et al. 1979; Miller et al. 1979).These data were acquired as part of the EPA Urban Rainfall-Runoff-Quality Data Base (Huber et al. 1979) and analyzed statistically to develop flow weighted average concentrations which were then used to develop surface runoff and interflow loadings to the lakes. The USGS data are appropriate for use in the study area because of similar meteorologic, hydrologic, and demographic characteristics of the locations. The USGS data also have the unusual advantage of a large number of samples, from 15 to 41 storms at the four sites of differing land uses.

Incorporating the various fluxes, the nutrient loadings shown in Table 3 are developed. Of interest is the influence of the lower layer on both T-N and T-P and the relative insignificance of urban run off on T-N.

IMPLICATIONS FOR LAKE WATER QUALITY

An assessment of predicted impacts on the lakes of the T-N and T-P loads may be performed using critical loading rate estimates developed by Vollenweider (1975) and Dillion and Rigler (1975), and specifically for Florida lakes, by Brezonik and Shannon (1971) and Kratzer (1979). Two sets of critical rates are given: those below which the lakes should remain oligotrophic; and those above which the lake should tend to eutrophy or suffer degraded water quality. These are compared in Table 4 with the loadings of Table 3.

On the basis of N:P ratios for the lakes, phosphorus is probably the most important relative to the prediction of trophic conditions. Phosphorus limitation is in fact typical of most lakes, with nitrogen limitation occurring only in unusual geological circumstances or for lakes receiving large loadings of sewage effluent (which typically has very low N:P ratios). Units 24 and 30 will be on central sewers and the proposed lakes will receive no sewage effluent.

The phosphorus loading rates for the lakes are at or below the excessive levels given by both Vollenweider (1975) and Brezonik and Shannon (1971). The lakes of Unit 24 receive higher loadings than those of Unit 30 in part because they have more deepwater with a large flux due to vertical diffusion. On the basis of the phosphorus loading rates, lakes in both units are expected to be mesotrophic with fair to good water quality.

The T-P concentrations in the lakes may be predicted using mass balance approaches in which the steady state concentration is a function of loading rate, detention time and mean depth (Dillion and Rigler 1975; Kratzer 1979). The predicted average T-P concentrations are 0.020 to 0.026 mg/l for Unit 24 and 0.014 to 0.019 mg/l for Unit 30, respectively, where the range results from using several different predictive relationships. These ranges are consistent with observed T-P concentrations in existing Lake Marco Shores.

On the basis of the nutrient loadings and T-P concentrations other parameters can be predicted by various regression relationships. On the whole, predicted water quality is good with Secchi disk transparencies on the order of 1.2 to 1.5 m and T-N of about 1.3 mg/l.

Chlorophyll *a* levels in the lakes have been predicted using correlations of average T-P vs. chlorophyll *a* reported in the literature (Dillion and Rigler 1974 and Kratzer 1979), and from reported predictive relationships between phosphorous loading rates and chlorophyll *a* levels (Kratzer 1979). Predicted chlorophyll *a* concentrations range from about 6 to 13 mg/m^3 in Unit 24 and from 3 to 13 mg/m^3 in Unit 30. These values are in the mesotrophic to slightly eutrophic range. Chlorophyll *a* is a commonly used trophic indicator, and it serves as a measure of algal biomass in lakes.

In summary, the predicted water quality parameters indicate that water quality in the proposed lakes will be satisfactory and that nutrient-overenrichment will not be a problem.

Table 3. Nutrietn loads tolakes in units 24 and 30.

	Unit 24	Unit 30
T-N Loads		
Surface + Interflow (lb/yr)	1096 (30%)[a]	5164 (32%)
Rainfall (lb/yr)	408 (11%)	3590 (22%)
Groundwater (lb/yr)	1879 (51%)	5618 (35%)
From Lower Layer (lb/yr)	289 (8%)	1746 (11%)
Total Load (lb/yr)	3672	16118
Normalized Loading[b]		
(lb/ac/yr)	45.9	22.9
(g/m^2/yr)	5.2	2.6
T-P Loads		
Surface + Interflow (lb/yr)	114 (51%)	514 (45%)
Rainfall (lb/yr)	28 (12%)	246 (21%)
Groundwater (lb/yr)	36 (16%)	108 (9%)
From Lower Layer (lb/yr)	47 (21%)	286 (25%)
Total Load (lb/yr)	225	1154
Normalized Loading[b]		
(lb/ac/yr)	2.81	1.64
(g/m^2/yr)	0.32	0.19

[a] Percent of total load.

[b] Loading = total load/watersurface area.

TABLE 4.
COMPARISON OF CRITICAL NUTRIENT LOADING RATES AND PREDICTED LOADINGS FOR UNIT 24 AND UNIT 30 LAKES

A. Critical Loading Rates

Reference	Loading Rate Units	Normalization Factors[a]	Lake	Oligotrophic Loading (up to) N	Oligotrophic Loading (up to) P	Eutrophic Loading (above) N	Eutrophic Loading (above) P
Brezonik & Shannon (1971)	Volumetric ($g/m^3/yr$)	$\bar{z}$	Both	0.86	0.12	1.5	0.22
	Areal ($g/m^2/yr$)	$\bar{z}$	Both	2.0	0.28	3.4	0.49
Vollenweider (1975)	Areal ($g/m^2/yr$)	q_s	24	--	0.14	--	0.28
			30	--	0.11	--	0.21
Dillon and Rigler (1975)	Areal ($g/m^2/yr$)	R_p, q_s	24	--	0.16	--	0.31
			30	--	0.14	--	0.27
Kratzer (1979):							
(1) Modified Vollenweider (1975)	Areal ($g/m^2/yr$)	q_s	24	3.1	0.17	6.3	0.35
			30	2.3	0.14	4.6	0.27
(2) Modified Dillon & Rigler (1975)	Areal ($g/m^2/yr$)	R_p, q_s	24	--	0.27	--	0.53
			30	--	0.23	--	0.46

B. Predicting Loading Rates for Unit 24 and Unit 30 Lakes

	Volumetric ($g/m^3/yr$) N	Volumetric ($g/m^3/yr$) P	Areal ($g/m^2/yr$) N	Areal ($g/m^2/yr$) P
Unit 24 Lake	2.4	0.178	5.2	0.32
Unit 30 Lake	1.4	0.106	2.6	0.19

[a] Normalization factors: physical variables needed to determine critical rate for a given lake from the loading plot, equation, or table of various authors. Values used are as follows:

Unit 24 Lake: $\bar{z}$ = 1.7 m, $_w$ = 0.57 yr, q_s = 2.97 m/yr, R_p = 0.81.

Unit 30 Lake: $\bar{z}$ = 1.7 m, $_w$ = 1.14 yr, q_s = 1.49 m/yr, R_p = 0.89.

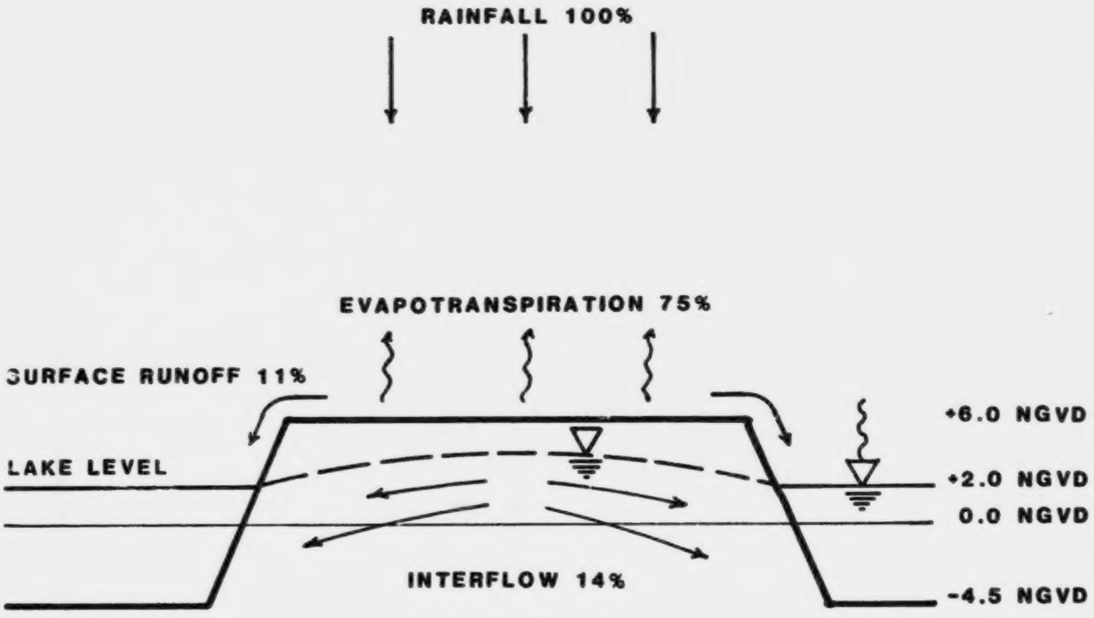
RAINFALL 100%
EVAPOTRANSPIRATION 75%
SURFACE RUNOFF 11%
LAKE LEVEL
+6.0 NGVD
+2.0 NGVD
0.0 NGVD
-4.5 NGVD
INTERFLOW 14%

FIGURE 1
THE LAND SURFACE WATER BUDGET

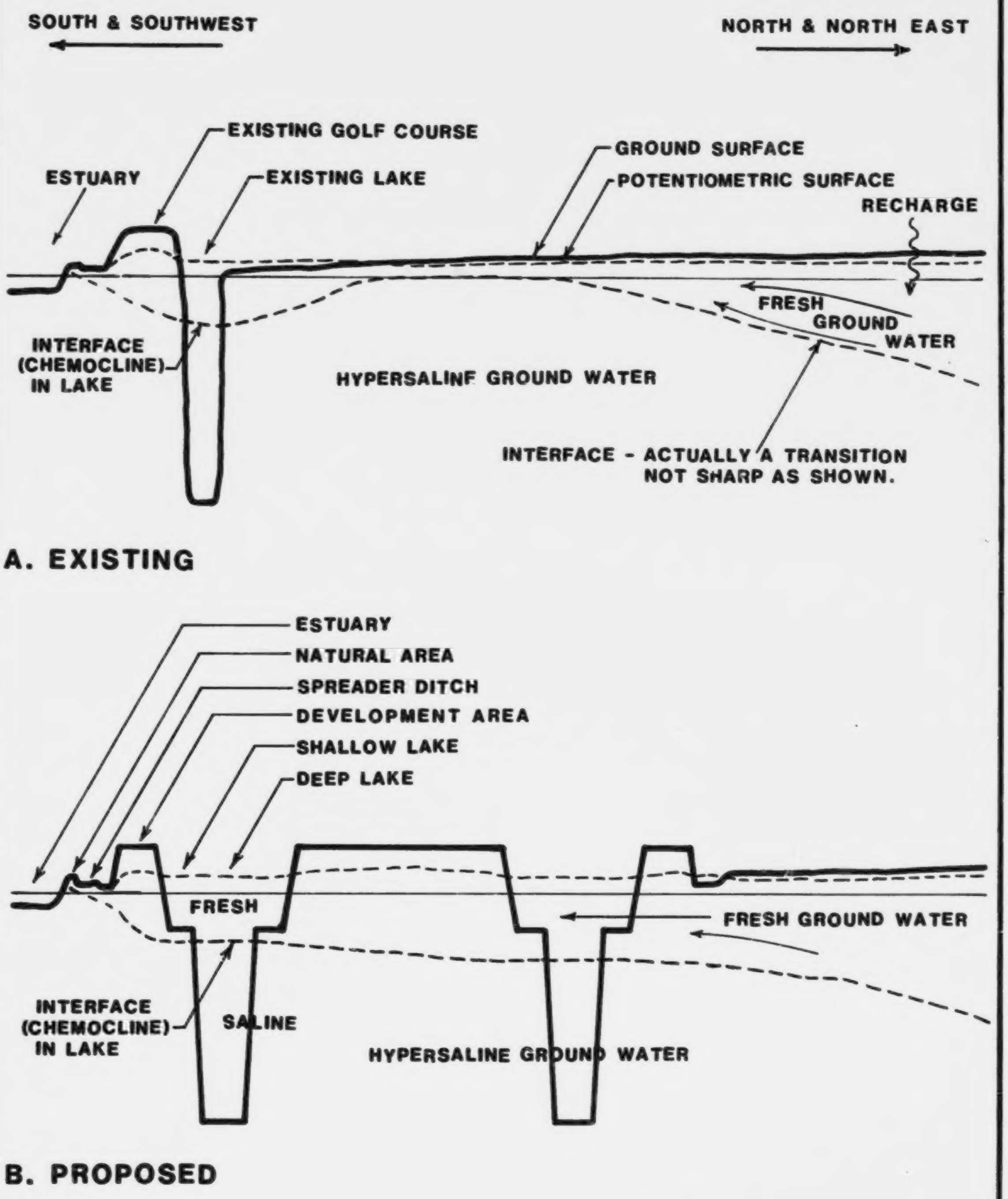
SOUTH & SOUTHWEST
NORTH & NORTH EAST
EXISTING GOLF COURSE
ESTUARY
EXISTING LAKE
GROUND SURFACE
POTENTIOMETRIC SURFACE
RECHARGE
FRESH
GROUND
WATER
INTERFACE
(CHEMOCLINE)
IN LAKE
HYPERSALINF GROUND WATER
INTERFACE - ACTUALLY A TRANSITION
NOT SHARP AS SHOWN.
A. EXISTING
ESTUARY
NATURAL AREA
SPREADER DITCH
DEVELOPMENT AREA
SHALLOW LAKE
DEEP LAKE
FRESH
FRESH GROUND WATER
INTERFACE
(CHEMOCLINE)
IN LAKE
SALINE
HYPERSALINE GROUND WATER
B. PROPOSED

FIGURE 2. REGIONAL GROUND WATER PATTERN.

DISCHARGES TO ESTUARIES

Using the predicted surface outflow rates and concentrations, discharges of T-P and T-N to the nearby estuaries may be computed as 65 kg/yr and 5,060 kg/yr, respectively, from the two units. These values are somewhat less than present discharges from the area due mainly to a reduction in surface outflows under the planned development. On the basis of nutrient loads, the urban development is expected to have little impact on the estuaries.

SUMMARY

Methods exist for prediction of lake and effluent water quality for the projected urban developments in southwest Florida. Analysis of nutrient budgets for the proposed lakes indicates mesotrophic conditions (fair to good water quality) with no deleterious effect on estuarine marshes.

ACKNOWLEDGEMENTS

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LITERATURE CITED

Brezonik, P.L.; Shannon, E.E. Tropic state of lakes in North Central Florida. Gainesville, FL: University of Florida; 1971. Water Resources Research Center Publ. 13.

Dillion, P.J.; Rigler, F.H. The phosphorus chlorophyll relationship in lakes. Limnol. Oceanogr. 19:767-773; 1974.

Dillion, P.J.; Rigler, F.H. A simple method for predicting the capacity of a lake for development based on lake trophic status. J. Fish. Res. Board. Can. 32: 1519-1531;1975.

Hardee, J.; Miller, R.A.; Mattraw, J.C. Jr. Stormwater runoff data for a highway area, Broward County, Florida. USGS Open File Report 78-612. Tallahassee, Florida, 1978.

Hardee, J.; Miller, R.A.; Mattraw, J.C. Jr. Stormwater runoff data for a multifamily residential area, Dade County, Florida 1979.

Huber, W.C.; Heaney, J.P.; Smolenyak, K.J.; Aggidis, D.A. Urban rainfall-runoff-quality data base, update with statistical analysis.Cincinnati, OH: U.S. Environmental Protection Agency. EPA Report EPA-600/8-79-004; 1979.

Kratzer, C.R. Application of input-output models to Florida lakes. Gainesville, FL: Dept. of Environmental Engineering Sciences University of Florida; 1979. 169 p. Thesis.

Mattraw, H.C. Jr.; Hardee J., Miller, R.A. Rainfall, runoff, water quality and load data for a residential area, Broward County, Florida. Tallahassee, FL: U.S. Geological Survey; 1978. USGS Open File Report 78-324.

Mattraw, H.C. Jr.; Sherwood, C.B. Quality of stormwater runoff from a residential area, Broward County, Florida. USGS Journal of Research 5:823-834; 1977.

Miller, R.A.; Mattraw, H.C. Jr.; Hardee, J. Stormwater runoff data for a commercial area, Broward

County, Florida.Tallahassee, FL: U.S. Geological Survey; 1979 USGS Open File Report 79-982.

Vollenweider, R.A. Input-output models, with special reference to the phosphorus loading concepts in limnology. Schweiz. Z. Hydrol. 37:53-84; 1975.

THE GROUND WATER FLOW SYSTEM IN THE VICINITY OF MARCO ISLAND, FLORIDA

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INTRODUCTION

The Deltona Corporation's planned development of a coastal area near Marco Island includes the creation of a series of interconnected lakes ranging in depth from a few feet to as much as thirty feet. Construction of these lakes will penetrate the water table aquifer in an area that is a mix of coastal wetlands and uplands. Because the lakes are to be created as part of a community development, one of the factors to be considered is the impact on water quality.

The previous section of this report revealed that both fresh and hypersaline water existed in Lake Marco Shores. Because of the geometry of the lake and the density difference between the two fluids, no mixing has occurred; a distinct boundary exists between the two. Hypersaline ground water also was found in shallow wells drilled in the vicinity of the lake. Much has been written regarding the effect of runoff on the quality of lake water; little has been written on the influence of ground water quality and the contribution of the ground water flow system. Accordingly, this study was conducted by Geraghty and Miller to investigate the influence of ground water on the proposed lake system. The principal goals were to estimate groundwater input to the property and to investigate fresh-salty ground water relationships in the vicinity of Lake Marco Shores.

METHODS

The study was based on evaluation of data collected from a variety of sources--an existing network of multi-zone monitor wells on the property, new multi-zone wells, exploratory and observation wells installed by the South Florida Water Management District (SFWMD), and information from published reports. In addition to an existing network of five multi-zone monitor wells on the property, multi-zone monitor wells were installed at five other locations on the property to provide more complete coverage. Two wells, 10 and 30 feet deep (3.05 and 9.14 meters) were installed at each site. Each well was sampled during drilling and geologic logs were prepared. After completion and development, water samples were collected from each well and sent to a certified laboratory where analyses for selected constituents were performed. The elevation of each well was determined so that water level measurements could be referenced to NGVD (National Geodetic Vertical Datum) and contour maps and cross-sections depicting the groundwater flow system could be prepared.

The observation well network was completed in late February 1980 during the dry season. Since then, Applied Environmental Services (AES) personnel have been measuring water levels periodically. These measurements have been used in preparing water table contour maps.

In addition to site-specific data, similar information from areas surrounding the property also has been used. Data on water levels, quality, and geology from a network of exploratory and observation wells installed by the SFWMD were used to depict regional conditions. The locations of all wells are given on Figure 1. Information also was obtained from a variety of published reports dealing with the hydrogeology of the general area.

RESULTS

SUBSURFACE CONDITIONS

The zone of interest in the study area consists of the upper 30 to 60 feet (9.14 to 18.3 meters) of sedimentary rocks formed by unconsolidated sand and limestone. A typical cross-section is illustrated in Figure 2. The section is drawn approximately parallel with the direction of groundwater flow. The entire area is overlain by a veneer of fine- to medium-grained clean, quartzitic sand (Pamlico Sand) with varying amounts of organic material. The upper one foot or so consists of silty, peaty material throughout much of the area. The predominant color of the shallower sand beds is tan to brown, owing to the presence of and staining by organic matter.

Deeper portions of the sand range in color from tan to gray. Clay and silt layers are not present. The thickness of the sand ranges from five to six feet north of the planned development to as much as 25 feet (7.62 meters) near the west end of Lake Marco Shores. In general, the sand is thicker along the southern part of the area near the lake and thinner to the north.

The Fort Thompson-Caloosahatchee Marl Formations (undifferentiated) underlie the sand throughout the study area. Typically, these formations consist of ±20 feet (6.1 meters) of a hard, sandy, shelly limestone. Marl is present in places. Near the bottom of this zone, cavities are frequently encountered. Most of the observation wells installed as part of the Geraghty & Miller field program penetrated cavities in the upper 20 feet (6.1 meters) or so of the limestone.

The Tamiami Formation underlies the Fort Thompson-Caloosahatchee Formations. The upper portion of the Tamiami Formation consists of the Ochopee Limestone member which is about 130 feet (39.6 meters) thick. This unit consists of abundant shell fragments and cavities, particularly above depths of about 80 feet (24.4 meters).

HYDROLOGIC CHARACTERISTICS

The Pamlico Sand and the underlying limestone formations form a single hydrologic unit, especially in the upper 80 feet (24.4 meters) or so. No clay or silt confining beds are present in the Pamlico Sand, and there appear to be no confining units in the limestone. Thus, the sand will transmit water to the limestone and vice versa, so that both the sand and limestone respond hydrologically as a single unit forming a water table aquifer in the area.

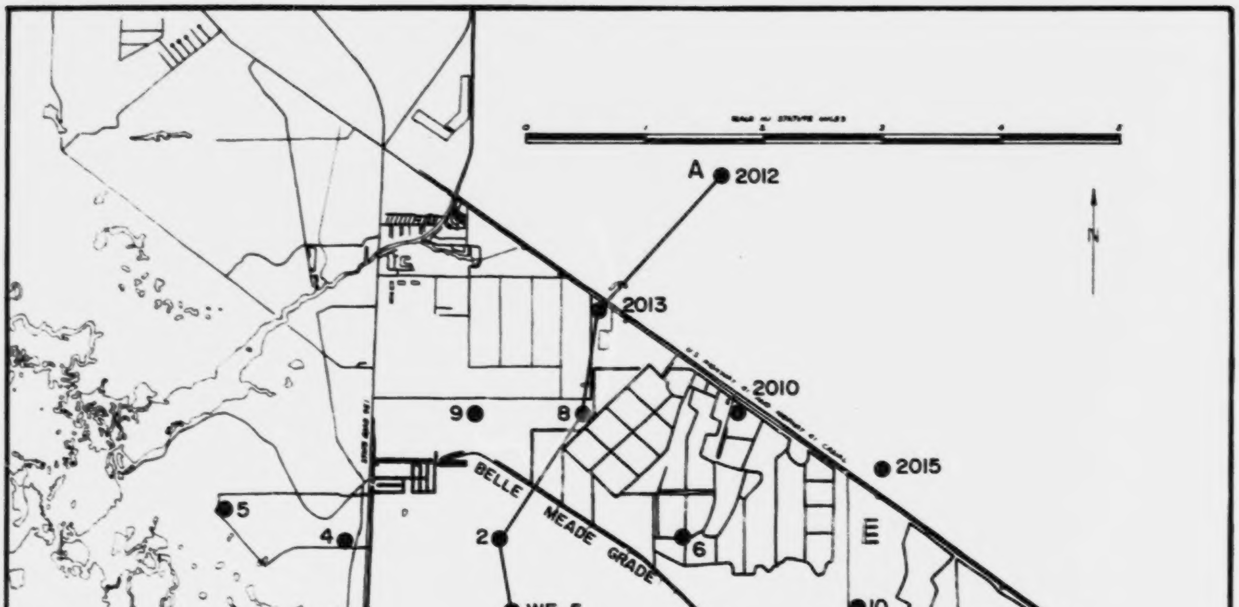
SCALE IN STATUTE MILES
0
1
2
3
4
5
N
A
2012
2013
2010
9
8
2015
BELLE MEADE GRADE
5
4
2
6
WE-5
10
7
1
A'
3

FIGURE I. LOCATION OF OBSERVATION WELLS AND SECTION A-A'.

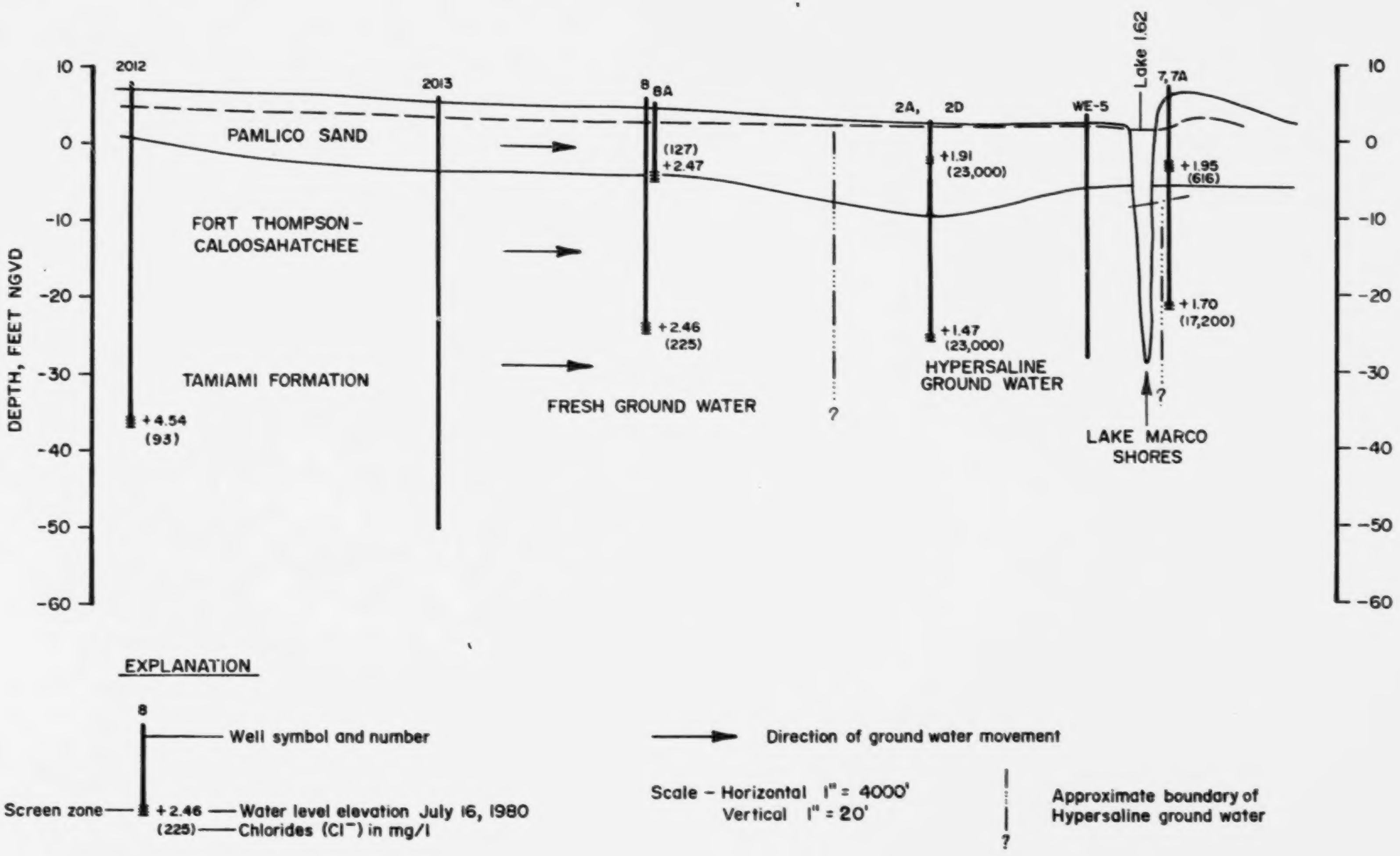
DEPTH, FEET NGVD
10
0
-10
-20
-30
-40
-50
-60
2012
2013
8
8A
2A,
2D
WE-5
Lake 1.62
7, 7A
PAMLICO SAND
FORT THOMPSON - CALOOSAHATCHEE
TAMIAMI FORMATION
FRESH GROUND WATER
HYPERSALINE GROUND WATER
LAKE MARCO SHORES
+4.54
(93)
(127)
+2.47
+2.46
(225)
+1.91
(23,000)
+1.47
(23,000)
+1.95
(616)
+1.70
(17,200)
?
EXPLANATION
Well symbol and number
Screen zone
+2.46 Water level elevation July 16, 1980
(225) Chlorides (Cl⁻) in mg/l
Direction of ground water movement
Scale - Horizontal 1" = 4000'
Vertical 1" = 20'
Approximate boundary of Hypersaline ground water

FIGURE 2. SECTION A-A'

Because of cavities and shell beds, the Fort Thompson Formation and Ochopee Limestone are extremely permeable and transmit water readily. Pumping tests conducted by the SFWMD on Well 2012 (220 feet or 67.1 meters deep) show that the transmissivity of the aquifer is 220,000 gallons per day per foot (2,732 m^2/day). Flow meter logging of this well revealed that about 95 percent of the water produced by the well is produced in the interval between the bottom of the casing at 12 feet (3.7 meters) and a depth of 60 feet (18.3 meters).

AREAL WATER QUALITY RELATIONSHIPS

During the studies conducted by AES and Geraghty & Miller, water samples were collected from the network of observation wells in 1978 and 1980. Analyses were performed for chlorides, specific conductance, and a number of other parameters. Because sodium chloride is a predominant constituent of sea water, the relationship between saline and fresh ground water in the area was determined by studying the distribution of the chloride ion (expressed as mg/l of Cl^-). Samples were analyzed from wells less than 10 feet (3 meters) deep, from wells tapping the principal water-bearing zone, and from the lake. The results, plotted on Figure 3, show the distribution of saline water in the area.

With the exception of the sample from Well 7, water from wells tapping the principal water-bearing zone and the deep portion of the lake contained chlorides well in excess of the normal concentration of sea water (18,000 to 19,000 mg/l): chlorides in Wells 1, 2, 3, and 5 ranged between 22,000 and 25,000 mg/l. Water from wells tapping the principal zone north of the Belle Meade Grade is salty to brackish ranging from 10,100 gm/l of Cl in Well 6 to 225 mg/l in Well 8. Proceeding northeast from the Belle Meade Grade, the chloride concentration of the ground water lessens. North of the grade, water from the shallow wells is fresh, less than 200 mg/l, with the exception of Well 6, where chlorides of 988 mg/l were found. South of the grade, water from the shallow wells ranges from 616 to 23,100 mg/l, while the shallow portions of the lake had chlorides of 3,661 mg/l.

The chloride concentration of the ground water north of the Belle Meade grade represent a normal distribution found in shallow aquifers in the coastal areas. Proceeding inland from the grade, the chloride concentration in the principal water-bearing zone diminishes; at Wells 8 and 10 the water in both zones is fresh for all practical purposes.

South of the grade, a different situation exists. The distribution of chlorides represents a combination of a unique natural condition and the results of man's activities. The hypersaline ground water present in both the shallow and the principal zones and in the lake is a natural condition. Normally shallow saline ground water in the coastal areas has the same composition as sea water. The observed chloride levels in excess of 18,000 to 19,000 mg/l, the concentrations found in sea water, require the presence of some mechanism of concentration. It is believed that the concentrating mechanism is one of or a combination of the following natural processes. The first possibility is evaporation. During periods of abnormally high tides, such as those accompanying hurricanes, the area will be inundated. When the tide recedes, pools of sea

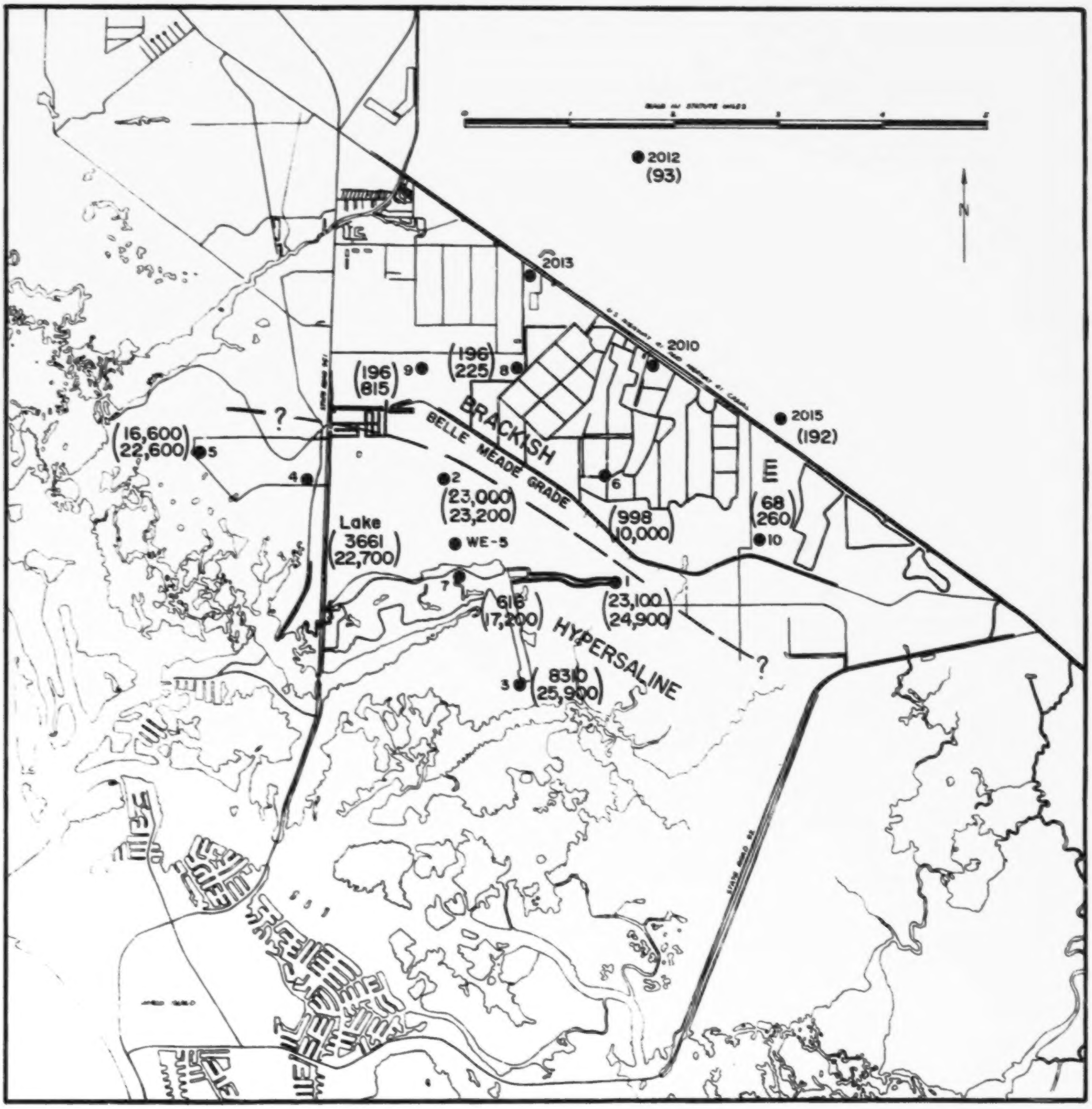
2012
(93)
N
2013
2010
2015
(192)
(196)
(815)
9
(196)
(225)
8
?
BRACKISH
BELLE MEADE GRADE
(16,600)
(22,600)
5
4
2
(23,000)
(23,200)
6
(998)
(10,000)
(68)
(260)
10
Lake
(3661)
(22,700)
WE-5
7
1
(616)
(17,200)
(23,100)
(24,900)
HYPERSALINE
?
3
(8310)
(25,900)

FIGURE 3. DISTRIBUTION OF CHLORIDES IN THE PRINCIPAL WATER BEARING ZONE, (Concentrations as Cl^- in mg/l).

Well number — 3 ● 8310 — Chloride concentration in shallow well less than 10 feet deep
25,900 — Chloride concentration in well tapping principal water bearing zone

Well samples taken March 1980
Lake samples taken May 1980

water are left behind in small, closed depressions. Before the water can seep into the ground, partial evaporation takes place and salinity increases. Eventually, the hypersaline water migrates downward, enters the water table, and becomes part of the ground water system. This process has been going on since the emergence of the area from the sea, so that the salinity of the ground water in the shallow aquifer in this area is greater than normal.

A second possible factor leading to hypersalinity is evapotranspiration. The water table is very close to the land surface virtually all of the time, so that evapotranspirative losses are high. Annual potential evapotranspiration is more than 53.1 inches (1,350 mm). The actual is estimated to be 39.4 inches (1,000 mm). While average annual precipitation at Fort Myers is about the same as the potential evapotranspiration, studies conducted on Marco Island (Weinstein et al. 1977) indicate that the coastal area has even less rainfall. Precipitation data for the years 1973 through 1977 from AES laboratory and Rookery Bay sites, which bracket the study area, indicate that the average rainfall is 8 inches (203 mm) less than at Fort Myers. Also, rainfall is not evenly distributed throughout the area so that there are periods when ground water recharge does not occur. Most of the precipitation occurs from May through October. For the remainder of the year very little rain falls. During these dry periods, evaporation from the water table undoubtedly occurs. Thus, a combination of the high potential evapotranspiration and the evaporative losses that undoubtedly occur during the dry months is believed to be one of the causes of hypersaline ground water.

Water from the deep and shallow zones at Well 7, located on the south side of Lake Marco Shores, had chlorides of 17,200 and 616 mg/l, respectively, on March 6, 1980, and 16.215 and 353 mg/l on May 1, 1980. Water from the deeper zone is less saline than sea water. The comparatively low chloride concentration present in water from the shallow well is a reflection of the presence of a lens of fresh ground water resulting from lake and golf course construction. Previously the area was a coastal marsh with conditions similar to those presently existing immediately to the north of the lake where hypersaline ground water exists. Consequently, fresh ground water could not have been present in such an environment prior to creation of the land.

When the golf course and airport were built, a mound or island of sandy material was created. Rainfall and golf course irrigation water percolated downward, eventually creating a lens of fresh ground water floating on more dense, saline ground water. Although potential evapotranspiration and rainfall are nearly equal in the area, there are times when rainfall exceeds the requirements of evapotranspiration and the surplus enters the ground, particularly where the soil is sandy. It is estimated that on a long term basis six inches of the normal yearly rainfall serves as recharge to the water table aquifer on the golf course, in addition to that which occurs as a result of irrigation.

Thus, over the years, a lens of comparatively fresh ground water has developed in the golf course area. The lens is dynamic; it is (on the average) constantly being replenished by rainfall while, at the same time, fresh ground water is being discharged to shallow portions of the lake (as well as to the south), one of the factors contributing to the relative freshness of water found in upper portions of the lake. Direct rainfall also aids in lowering the salinity of the water in the shallow portion of the lake.

GROUNDWATER FLOW

As noted previously, the flow system is dynamic; ground water is in constant motion. As water is added to the system in the form of rainfall recharge, discharge occurs along the coast. On a long-term basis, recharge and discharge are approximately equal. Variations do occur as a result of seasonal and annual differences in rainfall.

One of the goals of the program was to develop an estimate of ground water underflow to the project area. Contour maps of the water level in the principal water-bearing zone were prepared and used to determine the direction of ground water flow and to compute volumes. A typical example is given in Figure 4. This map is based on data collected on July 16, 1980, after the start of the rainy season. Maps based on data from other times during the study period show essentially the same overall relationship except that the water level elevations are somewhat different due to variations in recharge. It should be noted that only data from wells in the northern part of the study area were used in determining the direction of ground water movement and developing estimates of the quantity of flow.

Data from wells south of Lake Marco Shores reflect the influence of man's activities. The data from Wells 1, 3, and 7, located on artificial fill areas, reflect the presence of the freshwater lens in an area where only saline ground water formerly existed. This has local influence on the lake, but has no influence on the groundwater system contributing flow to the area from the northwest. Examination of Figure 4 shows that the elevation of the water table rises gradually, proceeding in a northeasterly direction from Well 2, indicating that the general direction of groundwater flow is toward the southwest.

The quantity of groundwater flow can be estimated from a modified version of Darcy's Law that is given by the expression:

$$Q = TIL$$

in which Q is the discharge in gallons per day, T is the transmissivity of the aquifer in gallons per day per foot, I is the hydraulic gradient expressed in feet per foot, and L is the width, in feet, of the cross-section through which flow occurs. Underflow estimates for the area were generated using a transmissivity value of 220,000 gpd/ft (2,732 m^3/day) and a hydraulic gradient based on the differences between the observed water level elevations in Well 2012 and Well 8 (Figure 1). These wells are located about 12,600 feet (3,841 meters) apart in a line that is approximately parallel with the direction of flow.

Water level measurements were taken at weekly intervals in these wells during the period of March through August 1980. During this period, the hydraulic gradient ranged between 1.3×10^{-4} ft/ft and 2.29×10^{-4} ft/ft, and averaged 1.79×10^{-4} ft/ft. The most representative value for the hydraulic gradient is the average one; the others represent values for the

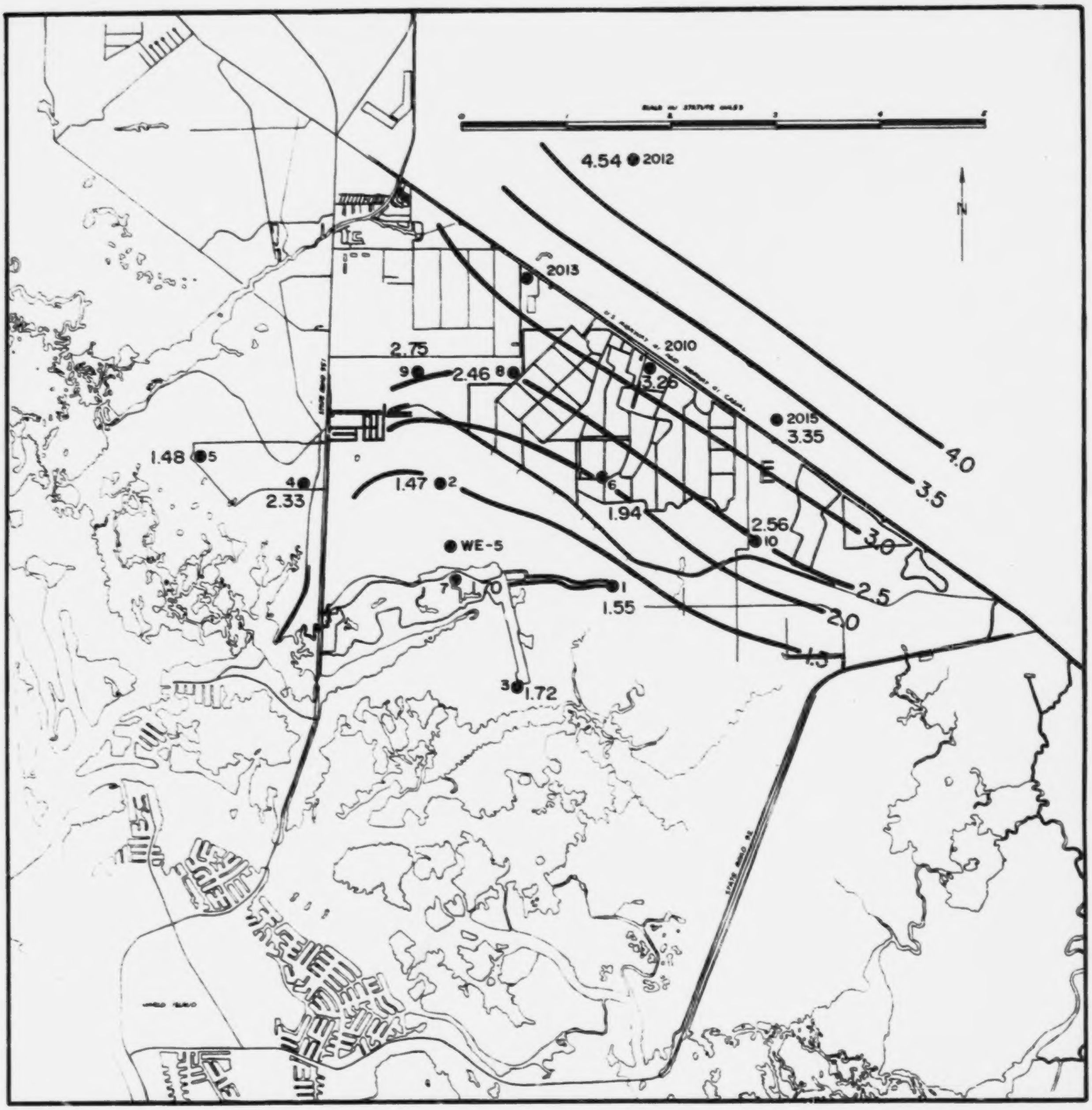
N
4.54 ● 2012
● 2013
● 2010
3.26
● 2015
3.35
4.0
3.5
3.0
2.5
2.0
1.5
E
2.56
● 10
● 6
1.94
2.75
9 ●
2.46
8 ●
1.48 ● 5
4 ●
2.33
1.47 ● 2
● WE-5
7 ●
1.0
● 1
1.55
3 ●
1.72

FIGURE 4. WATER LEVELS IN THE PRINCIPAL WATER BEARING ZONE, JULY 16, 1980.

● 2015 — Well number
3.35 — Water level elevation, in feet (NGVD)

—2.5 Water level contour

gradient at the times of measurement. However, the system is a dynamic one, with ground water moving slowly toward the discharge points so that changes in the system occur slowly. Consequently, the most representative value for flow is the average value.

Based on the average value for the gradient and the transmissivity value stated previously, the average groundwater flow is equal to 39.44 gallons per day per linear foot (0.49 meters^3 per day per meter) of aquifer width, or 208,000 gallons per day per linear mile (489 meters^3 per day per kilometer) of aquifer. This quantity moves into the area each day on the average. Eventually it discharges to saline bodies of surface water and is evaporated from the water table.

Behavior of the flow system and water quality relationships in the principal water bearing zone can be seen in the cross-section given in Figure 2. The elevation of the water table was highest at +4.54 ft (+1.38m) NGVD on the upgradient end of the section, at Well 2012, on July 16, 1980; at Well 8 it was +2.46 ft. (+0.75 m) NGVD, and +1.47 ft. (+0.45 m) NGVD at Well 2, showing that ground water was moving to the southwest from areas of higher head or water level elevations to ones of lower head (sea level). For a discussion of the fundamentals of ground water flow, the reader is referred to Freeze and Cherry (1979).

The data presented in Figure 2 and from the other wells show that the chloride concentration of the water in the principal zone increases as the marshes and bays are approached. For example, at Well 2012 the water had a chloride concentration of 93 mg/l; at Well 8, chlorides of 225 mg/l are present, whereas at Well 2 the chlorides were found to be 23,000 mg/l. As noted previously, the presence of the hypersaline water is anomalous and attributed to a combination of evaporation of the water table and the downward infiltration of tidal sea water whose density has been raised by evaporation. This is a process that has been going on for many thousands of years.

Figure 2 also shows relationships between water levels and quality in the lake and between different depth zones at the site of Well 7. At the time of measurement, the water level in the lake was at a lower elevation (+1.62 ft or + 0.49 m NGVD) than in both zones at Well 7, showing that ground water was discharging into the lake. In the shallow zone, the water level stood at +1.95 feet (+0.59 m) NGVD and the chlorides were 616 mg/l, while the water level in the deep zone stood at +1.70 feet (+0.52 m) NGVD and the chlorides were 17,200 mg/l. The observed chloride values are a reflection of the presence of the fresh water lens that has developed in the artificial land area and a local phenomenon which influences the quality of the water in the shallow portion of the lake. The higher level of chlorides present in the deep zone probably represent the zone of diffusion between fresh and salty ground water.

Water level data from deep and shallow zones at Well 2 give an additional clue as to why the ground water is hypersaline. Both zones contain water with about 23,000 mg/l of other chlorides. As shown in Figure 2, the water level on July 16, 1980 was +1.91 feet (+0.58 m) NGVD in the shallow zone and +1.47 feet (+0.45 m) NGVD in the deep zone. The higher head or elevation in the shallow zone indicates the downward movement of ground water. This relationship was observed following a period of rainfall. Comparison of the water level data from the two zones shows that for much of the time the relationship is reversed. Water levels in the deep zone stand at higher elevations than in the shallow zone. Indicating that ground water is moving upward or discharging. This phenomenon occurs during periods of little or no rainfall. During those times, water levels in the shallow zone decline in response to evaporative losses from the water table. During the seven months of the study, this condition prevailed most of the time, and is taken as additional evidence that evaporation is one of the mechanisms resulting in the formation of hypersaline ground water.

ACKNOWLEDGEMENTS

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LITERATURE CITED

Climates of the states, Volume 1. Eastern states plus Puerto Rico and the U.S. Virgin Islands. A practical reference containing basic climatological data of the United States. Washington, DC: NOAA. U.S. Department of Commerce; 1974.

Dohrenwend, R. E. Evapotranspiration patterns in Florida. Gainesville, FL: University of Florida, School of Forest Resources and Conservation; 1977.

Ferris, J. G.; Knowles, D. B.; Brown, R. H.; Stallman, R. W. Theory of aquifer tests. Washington, DC: U.S. Government Printing Office; 1962. Geological Survey Water Supply Paper 1536-E.

Freeze, R. A.; Cherry, J. A. Groundwater. Englewood Cliffs, NJ: Prentice-Hall, Inc.; 1979.

Jakob, P. G. Some aspects of the hydrogeology of coastal Collier County, Florida. Paper presented at the 1980 meeting of the Southeastern Geologic Society. West Palm Beach, FL; 1980.

Klein, H. Ground water resources of the Naples area, Collier County, Florida. Tallahassee, FL: Florida Geological Survey; 1954; 64 p. Report of Investigation No. 11. 64 p.

Kreitman, A. Water management and regulation of water use. In depth report. Central and Southern Florida Flood Control District; April 1975.

Mackenzie, F. T.; Gassels, R. M. Chemical mass balance between rivers and oceans. Ketano, Y., ed. Geochemistry of water. Stroudsburg, PA: 1975.

Parker, Garald G.; et al. Water resources of southeastern Florida. Washington, DC: 1955; 965 p. Geological Survey Water Supply Paper 1255.

Weinstein, M. P., Courtney, C. M.; Kinch, J. C. The Marco Island estuary: a summary of physiochemical and biological parameters. Fla. Sci. 40(2):97-124; 1977.

White, W. A. The geomorphology of the Florida peninsula. Tallahassee, FL: Florida Bureau of Geology; 1970. 164 p. Geological Bulletin 51.

SUMMARY OF PAPERS DESCRIBING RESTORATION OF FRESHWATER INFLOW TO AN ESTUARY IN CONJUNCTION WITH URBAN DEVELOPMENT

The Marco Island development proceeded concurrently with changing wetland regulations. Permits to construct sold lands were denied. The developer has proposed a substitute plan calling for development of 1,500 acres of uplands and 2,500 acres of wetlands located near the estuary. 13,000 acres of wetlands would be placed in "preservation" status. A key feature of the new plan is the proposed restoration of freshwater inflow to fringing estuary wetlands impacted by prior construction of roads and drainage works.

Vegetation in the general area now proposed for development grades from farmlands and uplands in the north to tidal mangroves in the south. Portions of the proposed development tract consist of a perched mangrove forest which lies within an artificial impoundment created by construction of a golf course, airport, and access road. The fill utilized in this construction came from a man-made lake. This man-made lake is approximately 30 feet deep and has become strongly stratified with approximately eight feet of fresh water floating above denser naturally occurring hypersaline ground water. The fresh surface layer has high dissolved oxygen and low nutrient concentrations. The chemocline is stable and observations indicate that neither wind nor temperature could cause an overturn. The saline lower layer has no dissolved oxygen and higher nutrient concentrations than the surface layer. The developer's additional proposed man-made lakes will have essentially the same characteristics as the existing man-made lake.

Ground water inputs to the proposed development area are calculated from observed groundwater contours and literature transmissivity values. Ground water in the shallow aquifer moves toward the coast with average flows of 208,000 gallons per day per linear mile of aquifer width. A freshwater lens replenished by rainfall and excess applied irrigation water exists in the filled land comprising the previously mentioned golf course. This freshwater lens may act as a piezometric barrier to groundwater flow to the south.

Measurement of present surface water runoff from the area has been facilitated because man-made alterations have diverted all runoff toward a set of three culverts. By continuously measuring the head difference across these culverts an accurate evaluation of runoff is obtained. Comparison with rainfall data yields a runoff coefficient of 53 percent (on a yearly basis). The above described golf course piezometric barrier may indicate that groundwater flows derived from areas north of the proposed development site become a component of the measured surface runoff. All surface runoff is presently channelized by roadside ditches directly to tidal waters changing timing, quantity, and location of pre-construction sheet flow discharge.

Water quality in man-made lakes in proposed developments is influenced by inflows from rainfall, surface runoff, interflow and ground water; and by outflows via surface runoff, ground water and evaporation. All flows are pathways for water quality constituents. These fluxes are evaluated for the proposed urban development, and nutrient loadings to the lakes determined. The study indicates good surface water quality in the proposed Unit 24 and Unit 30 lakes as evaluated from the loadings and physical characteristics. Of special interest is the presence of a mixolimnion and monimolimnion in the lakes separated by a chemocline exhibiting very strong density stratification.

Restoration of freshwater inputs to estuarine wetlands impacted by prior construction of roads and drainage works is accomplished by blocking all present channelized flows. Fresh surface water from the proposed real estate lakes will overflow to spreader waterways and then migrate via sheet flow across preservation wetlands to the estuary. The system design incorporates management flexibility--all lakes are interconnected--and sheet flow discharge can be routed via adjustable weirs to particular adjacent fringing wetlands that can be improved by increasing freshwater inflow.

DISCUSSION

Question: Pete Rosendall, Everglades National Park, directed to Dr. Huber. My question concerns the water quality analysis on the outflow from the proposed area. You settled on N and P as a way to address the question of the water quality in the adjacent area. I was wondering what sort of consideration is given to other parameters such as contaminants that aren't nutrients, and what control would the developer have over inputs from a residential area, such as somebody changing the oil in their car and pouring it in your lake? I don't see the beneficial effect of other than the nutrient outflow. The second part of my question is--approaching the problem from a nutrient balance, what's the difference of the nutrient output between the one calculated and the one that is currently occurring from this area? Is there a net increase and decrease in N and P on the proposed project?

Answer: In terms of other parameters, that would enter the lake there is a whole laundry list of things that could come in. We did investigate some, for instance, dissolved oxygen which we don't anticipate to be a problem. Bacteria we don't anticipate to be a problem. Other things, such as oil and grease, pesticides, herbicides, metals, and other things that we would not like to see in the lakes will be contained in the urban runoff because they've been measured in many different places. The control on those is for all of the residential street and commercial development to be passed through swales. There will not be any pipes running into the development. So hopefully the soil system, the vegetation system and so forth will act as a filter for many of these things. In other developments, the use of certain pesticides and herbicides has been prohibited either by law or at least the developer has been prohibited from using them, so there is some restriction on these. There will also be a littoral zone on the lake. The lakes will all be established with a five to one slope, that is, one vertical and five horizontal, with vegetation and so forth to act as filters. The main control is to try to keep the pollutants out in the first place. The other question you asked concerning the nutrients N and P will be less in the new development than they are now.

Question: From a biological point of view, have any of the investigations that have been carried out there looked at the transport or restriction of particular material via the culverts or associated with the culverts?

Answer: In this part of the study I have addressed the issue of carbon export through these culverts, and we found that carbon export was perhaps 97 percent in dissolved form, and maybe 3 percent in particulate form. The output of carbon through those culverts in all forms of organic carbon amounts to about a ton a day. So these culverts are presently supplying something like one to two percent of regional supply to the estuary.

Question: Richard Baily, Department of Housing and Urban Development. I have two questions. First, what's the mechanism by which you would control the use of pesticides, and so on, that might run off in the lake, and will it be deed restricted, or what?

Answer: One way that we would have in our power to incorporate would be a property owner's association and some deed restrictions which would place those kind of limitations. Then the question is, what would be the target substances? We would probably just rely on the Federal government to determine which were the most important.

Question: The second question is--if you got about 44 inches of evaporation on your budget going out, have you compared that to a similar size and type area with natural evaporation or sheet flow, and how do they compare?

Answer: The 44 inches is 70 percent of pan, and that's what we use for a lake. For the natural areas in the region, it's about 75 percent of rainfall. Rainfall is about 55 inches, so 75 percent of 55 is something less than 44-40 inches. So the lake evaporation would be a little bit more, probably, than the evapotranspiration from the natural area.

Question: I have two questions. First of all, have you considered, or is it even a problem, with the potential work that they may be doing in the Golden Gate Estates area, and the installation of the flash boards to help retain some of the water in that area? And secondly, in the application of pesticides the current method is by aerial spraying and also spraying by truck. How are you going to control the application of Baytex which they are currently using ? Baytex is a non-specific killer of a number of organisms and if this gets into the lakes, aren't you going to have considerable trouble biologically with the organisms that will and won't grow there? In terms of possibly having weeds growing because there's no organisms to eat them?

Answer: I can take a stab at that in terms of Golden Gate. I think that anything that slows down the loss of water to the estuary is a positive development. I think that somebody stated that the water going over the discharge point that is shown on that big photo over there is enough to supply a city of four million and it is water that is lost to the estuary. The second question on pesticides, we don't have a lot of control over what the county does in terms of their mosquito control district. On the local basis, though, the home owners association will own the perimeter of the lakes, that is, the association will own the 15 feet of lots that front on the lakes. The entire perimeter of this project will be in common ownership. The opportunities that provides in terms of the control of the overall application pesticides, I don't know. I think you can expect, though, that with the number of people living there, the pesticide problem is one to be dealt with.

CHAPTER 3

FISHERIES MANAGEMENT AND FRESHWATER INFLOW

THE EFFECTS OF FRESHWATER DISCHARGES ON SPORTFISHING CATCH RATES IN THE ST. LUCIE ESTUARY, MARTIN COUNTY, FLORIDA

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ABSTRACT

The St. Lucie River is a 6,000-acre estuary located on the east coast of Florida. It is the eastern outlet of fresh water released from Lake Okeechobee through the St. Lucie Canal. The primary purpose of the releases is for flood control. Neighboring communities depend heavily on tourism and are concerned about the effects that the freshwater discharges and associated silt loads have on fishing success. A creel census was conducted by the U.S. Fish and Wildlife Service for one year. Multiple-source, stepwise regression analysis and ridge regression analyses were performed on the freshwater discharge and creel data to determine if catch rates are affected by the St. Lucie Canal discharges, and, if so, in what part of the estuary they are affected. It was determined that snook, croaker, sheepshead, mullet, black drum, weakfish, gafftopsail catfish, gray snapper, and Irish pompano catch rates were significantly affected by moderate discharges.

INTRODUCTION

The St. Lucie River is a small estuary of approximately 6,000 acres located in Martin and St. Lucie counties on the southeast coast of Florida. The North and South Forks, constituting the inner estuary, converge at the City of Stuart, where the river widens to one mile after passage beneath the Roosevelt Bridge. Approximately three miles east, the river bends to the south, extending to the southernmost extension of Sewall Point, a spit of land separating the St. Lucie River from the Indian River (a coastal lagoon) to the east. At this point, both bodies of water empty into the Atlantic Ocean at the St. Lucie Inlet (Figure 1).

Fresh water enters the St. Lucie Estuary from three natural sources: direct rainfall runoff and groundwater seepage. Three man-made drainage canals add to the drainage area that already includes parts of Okeechobee, Martin, and St. Lucie counties. The St. Lucie Canal, which discharges into the South Fork, is of primary concern in this study as one of the major outlets for regulatory discharges from Lake Okeechobee.

Historically, Lake Okeechobee overflowed infrequently into the Everglades in the southern part of the State. As the population increased south of Okeechobee and hurricane flood damages occurred, with need for more predictable drainage became apparent. A state agency,

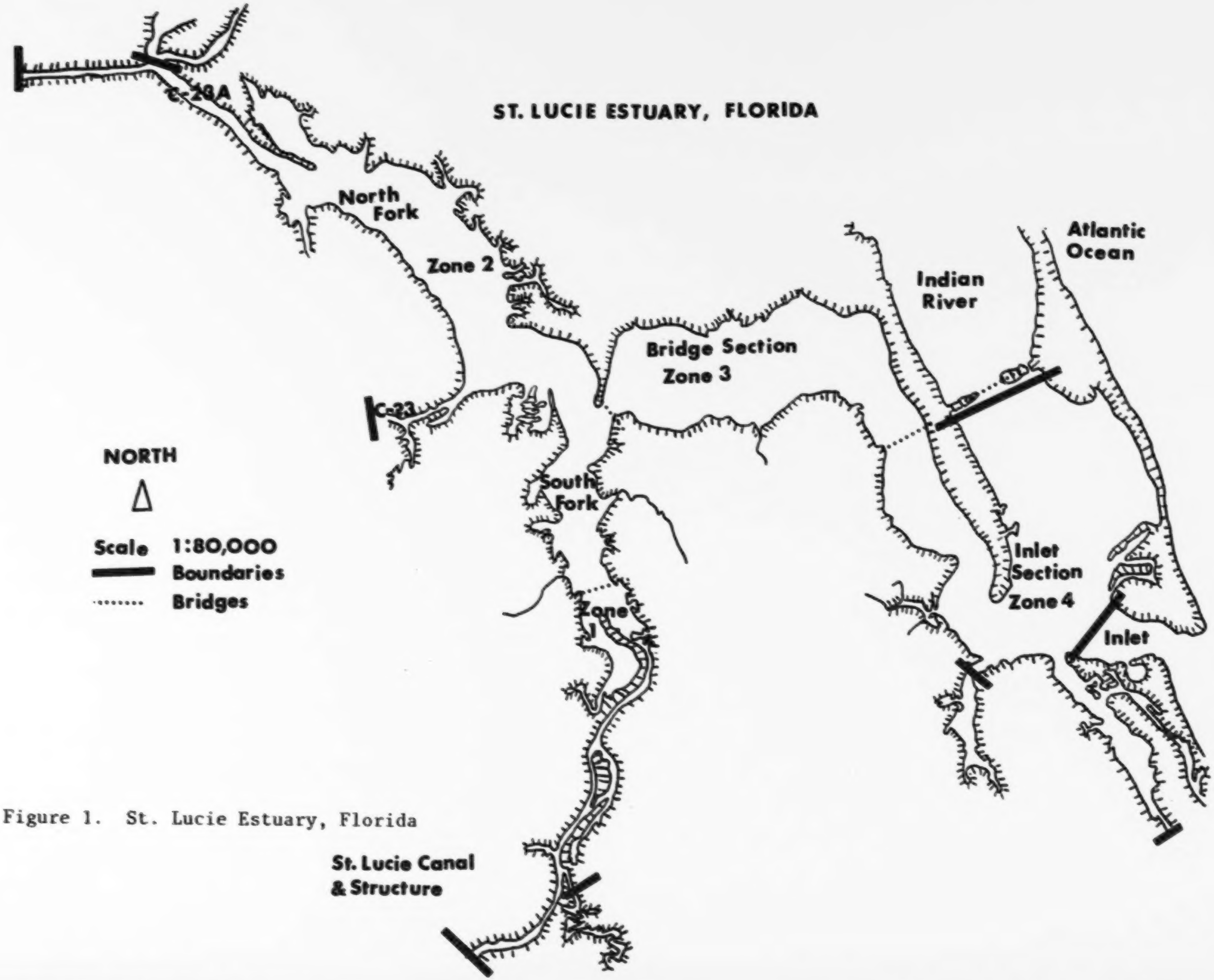
ST. LUCIE ESTUARY, FLORIDA
C-23A
North Fork
Zone 2
Indian River
Atlantic Ocean
Bridge Section
Zone 3
C-23
NORTH
South Fork
Scale 1:80,000
Boundaries
Bridges
Zone 1
Inlet Section
Zone 4
Inlet
St. Lucie Canal
& Structure

Figure 1. St. Lucie Estuary, Florida

the Everglades Drainage District, dug the St. Lucie Canal between 1916 and 1924 to help control flood waters from Lake Okeechobee. It was connected to the South Fork of the St. Lucie River and, when opened, had a discharge capacity of 5,000 cubic feet per second (cfs). Control of the canal was transferred to the U.S. Army Corps of Engineers in 1930. The discharge capacity was expanded to 9,000 cfs (with the lake stage at 15.6 ft) in 1949.

The problems involved with the St. Lucie Canal discharges, in contrast to some Texas estuaries, involve the inflow of too much fresh water to the estuarine system. Moderate flows from the St. Lucie Canal structure combined with two agriculture canal releases into the North Fork of the river are a little less than one-half the magnitude of flow into the San Antonio Bay System. However, the St. Lucie measures only one-twentieth the surface area. This imbalance in augmented freshwater inflow has caused concern about salinity structure, sedimentation and associated turbidity.

Scientific studies aimed at species diversity were concluding that the St. Lucie Canal discharges were either beneficial to the estuary (Gunter and Hall 1963) or that limited discharges had no detrimental effect (Haunert and Startzman 1980). Fishermen and those involved in the tourist trade were not satisfied. Claims were made that the high turbidity, resulting from the discharges, caused decreases in catch rates, the pushing of sportfishes out of the estuary and a subsequent drop in angler use.

The Fish and Wildlife Service, under authorization of the Fish and Wildlife Coordination Act and, in conjunction with the ongoing study of the Okeechobee Waterway Project, was funded by the U.S. Army Corps of Engineers to perform a creel census with a statistical analysis correlating freshwater discharges and fishermen's catch-per-unit of effort. In addition, this data was compared to creel census and pressure estimates collected on the river in the late 1950's to get an idea of some of the long-term effects of the discharges.

MATERIALS AND METHODS

For 13 months, between June 1978 and July 1979, a creel census team systematically surveyed the St. Lucie Estuary system for data concerning the catch of bridge, boat, dock, and wading fishermen. The results of this investigation were correlated with information on freshwater releases.

LIMITATIONS OF FIELDWORK

It should be noted here that the data collected express conditions during June 1978 through July 1979. Predischarge values are lacking, therefore, conclusions are based entirely on data collected under the influence of alterations. In addition, all harvest and catch rates have been calculated from interviews performed from sunrise to sunset. Due to manpower limitations and the obvious navigational problems, no sampling was done at night. In addition, to facilitate the systematic sampling necessary for the time series analysis, data were collected only on Tuesdays, Thursdays, Saturdays, and Sundays.

DESIGN CONSIDERATIONS

The estuary was divided into four zones, each one having demonstrated in earlier studies distinct regional effects of the St. Lucie Canal freshwater discharges. To study variations in catch-per-unit of effort over time as correlated with discharges, the typical stratified random sampling plan over days, periods and zones was waived in favor of a systematic plan using a 4 x 4 Latin square design to obtain weekly estimates.

SINGLE-SOURCE, CROSS CORRELATION ANALYSES

Single-source cross correlation analyses, lagged up to 20 weeks, were done to determine what effects the following six inflow characteristics had on fishing pressure: (1) week rain (total weekly rainfall); (2) average St. Lucie daily flow/week; (3) average C-23 daily flow/week; (4) combined average C-23 and C-23A daily flow/week.

The results are summarized as estimated lagged correlations. The critical value for testing the significance of the estimated cross correlations was 0.324 for a 5 percent test.

MULTIPLE-SOURCE STEPWISE REGRESSION ANALYSIS

The primary purpose of this study was to examine the effects (if any) of St. Lucie Canal inflow on the fish catch rates in the estuary. Therefore, six characterizations of freshwater inflow from the St. Lucie Canal, as well as the two agricultural canals, C-23 and C-23A, were identified.

A stepwise regression procedure was utilized (SAS Procedure STEPWISE) and adapted to selecting only that subset of predictors whose assigned regression weights are significantly different from zero. The available set of predictors consisted of 63 variables chosen from six weeks of leading values taken from inflow variables, with the level of significance for retention in the model set at 10 percent. This method has a clear advantage of simulating a situation in which inflows from C-23 and C-23A are held constant while the relationship between St. Lucie inflow and catch rate is being examined. The coefficient of determination, designated as R^2, represents an estimate of the fraction of the total variation in catch rate series which can be accounted for by the respective series of the selected set of predictors.

FINAL MODEL SELECTION/RIDGE REGRESSION ANALYSIS

Using the results of the stepwise regression analysis, the following criteria were used for evaluating the importance of the St. Lucie Canal flow on species catch rates: (1) there had to have been considerable variation in the catch rate over time for the species under consideration; (2) the forcing of St. Lucie variables on an existing model in order to define a second model should account for a considerable increase in the fraction of the total variance accounted for, 0.05 or more, as reflected by the difference $R_1^2 - R_2^2$; (3) essentially the same St. Lucie variables should be selected when presented initially as when forced (as in the second model), otherwise one would conclude that there was considerable redundancy among the predictors; and (4) the fraction of the total variance accounted for by the forced St. Lucie variable model and the equally presented St. Lucie variable model should be sizable, 0.30 or more. Otherwise, one would argue that the appropriate predictor variables simply were not made available for selection. If they were, it is likely that they would dominate or even replace the effects of the St. Lucie variables. After a tentative model had been selected by the foregoing proceedings, ridge regression analysis was performed to examine the stability of the regression coefficients.

COMPARISON WITH EARLIER STUDIES

Two resource reports were written about the St. Lucie River by the Fish and Wildlife Service, Vero Beach, Florida office in the late 1950's. (U.S. Department of the Interior, Fish and Wildlife Service 1959, 1960). Comparisons of the raw data from those early studies with current estimates of the sportfishing catch were made. Using the analysis techniques from the old report, the current raw data were converted to a similar comparable form.

RESULTS

In response to outcries that declared the St. Lucie River a "biological desert," the Corps of Engineers agreed to limit eastward discharges from Lake Okeechobee to 2,500 cfs whenever possible. The study team was fortunate to have had three releases to that level within the sampling period. One was the scheduled release in the beginning of the summer of 1978 and the other two were the consequence of heavy rainfall. Our results, therefore, can be interpreted as being representative of fishing conditions on the estuary as affected by the present schedule for normal allowable discharges.

Overall, during the one-year period from June 1978 through June 1979, 440,399 acre-feet were released through the St. Lucie Canal, 91,260 acre-feet through C-23, and 88,187 acre-feet through C-23A. In addition, a total of 49.29 inches of rain fell on the estuary. Three distinct rainy periods correspond to high weekly cumulative discharge rates from each of the three discharge structures.

SINGLE-SOURCE, CROSS CORRELATION ANALYSES

Single-source, cross correlation analyses (Table 1) indicate that neither rain nor the St. Lucie Canal discharges had significant correlations with fishing pressure. The agricultural canals, on the other hand, affected pressure with some indications that discharges in the North Fork may increase South Fork fishing pressure while decreasing pressure in the North Fork and inlet sections.

MULTIPLE-SOURCE, STEPWISE REGRESSION ANALYSES

Fifteen species of fish, chosen from the 56 species sampled, either because of their importance as sport fishes or their significant harvests, were tested for correlations with St. Lucie Canal discharges. These fish

Table 1. Cross correlation results significant for pressure (5% test, 0.324).

Sign of Correlation	Zone	Source	Lag
+	1	Ave. C-23A flow	6 wks.
-	2	Ave. C-23 flow	1 wk.
-		Ave. C-23 & Ave. C-23A flow	1 wk.
No significant corr.	3		
-	4	Ave. C-23 flow	4,5, & 16 wks.
-		Ave. C-23A flow	2 & 3 wks.
-		Ave. C-23 & Ave. C-23A flow	3 & 4 wks.
-	Estuary	Ave. C-23 flow	4 & 5 wks.
-		Ave. C-23 & Ave. C-23A flow	4 wks.
No significant corr.		St. Lucie Canal	
No significant corr.		Weekly cumulative rainfall	

were: gafftopsail catfish (*Bagre marinus*), sea catfish (*Arius felis*), croaker (*Micropogon undulatus*), black drum (*Pogonius cromis*), flounder (*Citharichthys* spp. and *Parlichthys* spp.), mullet (*Mugil* spp.), Irish pompano (*Diapterus olisthostomus*), pinfish (*Lagodon rhomboides*), puffer (*Sphoeroides testudineus*), sheepshead (*Archosargus probatocephalus*), snook (*Centropomus* ssp.), weakfish (*Cynoscion* spp.), spotted seatrout (*Cynoscion nebulosus*), whiting (*Menticirrhus americanus*), and gray (mangrove) snapper (*Lutjanus griseus*).

With emphasis on the St. Lucie Canal discharges, species were chosen from the results of the multiple regression analyses which best fit the criteria outlined in the methods section. The results of those criteria produced the following list of species whose catch rates were significantly affected by the St. Lucie discharges and whose catch records were relatively regular.

South Fork = Zone 1:	Gray (mangrove) snapper and mullet
North Fork = Zone 2:	Snook, sheepshead and croaker
Bridge Section = Zone 3:	Snook and black drum
Inlet Section = Zone 4:	Gafftopsail catfish, croaker, weakfish, gray snapper and black drum
Entire Estuary:	Croaker, mullet, Irish pompano and snook

Regression analysis indicated that there were no significant effects instantaneously on the catch rates of any of the above species (Table 2). However, after a lag of one week following maximum daily flow for a week, there was an increase in the catch rate of gray snapper, croaker and weakfish in the inlet section. There was a lag of four weeks after average St. Lucie Canal discharges, resulting in another correlation involving catch rate increases in the inlet section of sheepshead, gafftopsail catfish and Irish pompano. As the total average flow above the median St. Lucie Canal discharge increased, the gray snapper and black drum catch rates significantly decreased in the inlet section.

While the inlet section was active as a result of the discharges, the snook catch rates oscillated between the North Fork and bridge section. After a lag of two weeks following average St. Lucie Canal discharges, the snook catch rate decreased in the North Fork; and the third week it increased in the bridge section; one week later it increased in the North Fork; it finally showed a decrease in the bridge section catch rate in the fifth week. Overall, as the length of the St. Lucie average flow increases, the snook catch rate for the estuary increased as well.

Croaker is also affected in the North Fork. After a lag of three weeks following average St. Lucie Canal discharges, catch rates decrease in the North Fork. After a lag of four weeks following behind maximum St. Lucie discharges, catch rates increased in the North Fork.

Although throughout the estuary a negative correlation with the

TABLE 2.
Effects of St. Lucie Canal discharges on catch rates (CPE) within the St. Lucie Estuary

LAG	South Fork Zone 1	North Fork Zone 2	Bridge Section Zone 3	Inlet Section Zone 4	Estuary
NO lag factor				Total ave. flow- L. griseus- DECREASED CPE Total ave. flow- P. cromis- DECREASED CPE	Length of ave. flow- Mugil spp.- DECREASED CPE Length of ave. flow-Centropomus spp.-INCREASED CPE
1 week				Max.-L.griseus INCREASED CPE Max.-M.undulatus- INCREASED CPE Max.-Cynoscion spp.- INCREASED CPE	
2 weeks		Ave.-Centropomus spp.- DECREASED CPE			Ave.-Centropomus spp.-DECREASED CPE
3 weeks		Ave.-M.undulatus DECREASED CPE	Ave.-Centropomus spp.-INCREASED CPE		
4 weeks		Ave.-Centropomus spp.-INCREASED CPE Max.-M.undulatus- INCREASED CPE		Ave.-A.probatocephalus- INCREASED CPE Ave.-B.marinus- INCREASED CPE Ave.-D.olisthostomus- INCREASED CPE	Ave.-D. olisthostomus- INCREASED CPE
5 weeks	Max.-Mugil spp.- INCREASED CPE		Max.-Centropomus spp.-DECREASED CPE		

Ave.= Average cfs flow for one week
Max.= Maximum cfs flow for one week
Total ave. flow = Any continuous average flow above the median weekly flow value
Length of ave. flow= Length of any continuous average flow above the median weekly flow value

length of average St. Lucie Canal flow exists for mullet, a five-week lag behind average discharges result in mullet catch rate increases down the South Fork.

Table 3 lists the additional influences of C-23 and C-23A discharges on the specific species and in the zones already selected as being significantly affected by the St. Lucie Canal discharges. Although this is not a complete look at the effects of the agricultural canals, it aids in the interpretation of St. Lucie Canal discharge effects. For instance, in interpreting the movement of sheephead, the influences of discharges from the St. Lucie Canal or C-23 alone do not indicate an exodus from the inner estuary to cause the increase in the catch rate in the inlet section. However, analysis of discharges from C-23A indicate that the first response is a decrease in catch rate in the North Fork followed by an increase in the inlet section. The analysis of C-23A flow has apparently captured subtleties in the change in rates that the other analyses have not.

PAST AND PRESENT SPORT FISHING PRESSURE

The total number of boaters in the North Fork and fishermen in the South Fork, bridge and inlet sections, was estimated to be 70,500 angler days spent in the late 1950's (Table 4). Estimated angler days for this 1978-79 study (including for comparison only the boaters from the North Fork) was 66,303. Based on a 25-year projection included in the Fish and Wildlife Service 1959 report, the current angler utilization is less than the actual 1956-57 survey and only 42 percent of the projected amount.

Over the years, species preferences in the North Fork have changed and diversified. However, the percentage of fishermen who are after certain species has remained about the same and snook still leads as the most preferred species. In terms of species that make up the harvest, snook has dropped from over 26 percent of the harvest to just over 2 percent in this survey. Croaker has also dropped significantly from 14.1 percent to only 3 percent of the harvest, whereas gray snapper has remained about the same. Three species that have greatly increased as a percentage of the harvest are bream or sunfishes which have moved from 1.3 percent to 19.3 percent, mullet which has increased from 0.5 percent to 18.9 percent, and the combined catch of weakfish and spotted seatrout which has increased from 0.5 percent of the harvest to 8.2 percent in this study.

North Fork catch-per-unit of effort was calculated for the months July through April. The puffer, mullet, and bream catches have significantly increased the catch rates for the summer months. In the 1956-57 survey, the most successful month was December. February, with a substantial contribution by bream, was the most successful month of this 1978-79 survey.

CONCLUSIONS

The catch rates of nine important fish species were found to be significantly influenced by the moderate freshwater discharges from the St. Lucie Canal, Stuart, Florida,

TABLE 3.
Additional influences of C-23 and C-23A discharges on the fish species in the zones specifically affected by the St. Lucie Canal discharges.

SPECIES	ST. LUCIE CANAL	C-23	C-23A
Lutjanus griseus	Total ave.flow-DEC.-Zone 4 Max-INC.-Zone 4-(1 wk)	Max-INC.-Zone 1-Instant. Ave..-INC.-Zone 4-(3 wk) Ave..-INC.-Zone 4-(5 wk)	Length of ave.-DEC-Zone 1 Ave.-DEC.-Zone 1-(3 wk)
Micropogon undulatus	Max-INC.-Zone 4-(1 wk) Ave.-DEC.-Zone 2-(3 wk) Max.-INC.-Zone 2-(4 wk)	Ave.-INC.-Zone 4-(3 wk) Ave.-INC.-Estuary-(3 wk) Max.-DEC.-Estuary-(3 wk) Ave.-INC.-Zone 4-(5 wk) Ave.-INC.-Estuary-(5 wk) Max.-DEC.-Estuary-(5 wk)	
Centropomus undecimalis C. parallelus	Length of ave.-INC.-Estuary Ave.-DEC.-Zone 2-(2 wk) Ave.-DEC.-Estuary-(2 wk) Ave.-INC.-Zone 3- (3 wk) Ave.-INC.-Zone 2-(4 wk) Max.-DEC.-Zone 3-(5 wk)	Ave.-INC.-Zone 3-Instant. Length of max-DEC-Estuary Max.-DEC.-Zone 3-(2 wk) Max.-DEC.-Zone 2-(3 wk) Max.-DEC.-Estuary-(4 wk)	
Archosargus probatocephalus	Ave.-INC.-Zone 4-(4 wk)	Ave.-INC.-Zone 4-(5 wk)	Max.-DEC.-Zone 2-(4 wk) Max.-INC.-Zone 4-(6 wk)
Mugil cephalus M. curema	Length of ave.-DEC-Estuary Max.-INC.-Estuary-(2 wk) Max.-INC.-Zone 1-(5 wk)		Length of max.-INC-Zone 1 Length of max.-INC-Estuary Max.-INC.-Estuary-(3 wk)
Pogonias cromis	Total ave.flow-DEC-Zone 4	Ave.-INC.-Zone 4-(3 wk) Ave.-INC.-Zone 4-(5 wk)	
Diapterus olisthostomus	Ave.-INC.-Zone 4-(4 wk) Ave.-INC.-Estuary-(4 wk)	Ave.-INC.-Zone 4-(5 wk) Max.-DEC.-Zone 4-(5 wk) Ave.-INC.-Estuary-(5 wk) Max.-DEC.-Estuary-(5 wk)	Total max flow-DEC-Zone 4 Length of max-DEC-Estuary
Cynoscion regalis C. nothus	Max.-INC.-Zone 4-(1 wk)	Ave.-INC.-Zone 4-(3 wk)	Ave.-INC.-Zone 4-Instant.
Bagre marinus	Ave.-INC.-Zone 4-(4 wk)	Max.-DEC.-Zone 4-(4 wk) Ave.-INC.-Zone 4-(5 wk) Max.-DEC.-Zone 4-(5 wk)	

Ave.=Average cfs flow for one week
Max.=Maximum cfs flow during one week period
Total ave.(or max.) flow = Any continuous average or maximum flow above the median weekly flow value
Length of ave. (or max.) flow = Length of any continuous ave. or max. flow above the median weekly flow value
DEC= decreased catch rate   INC= increased catch rate   (# wk) in parentheses indicates lagged correlation

Table 4. Past and present sportfishing pressure for the St. Lucie Estuary, Florida.

	Angler Days '56-'57	25 Year Profected Angler Use[3]	Value at Current Levels[4]	Angler Days '78-'79	Actual Value
North Fork Boaters[1]	7,500	16,900	$182,013	6,311	$67,969
South Fork, Bridge & Inlet[2]	63,000	141,750	$1,526,648	59,992	$646,114
Totals			$1,708,661		$714,083

1/ U.S. Dept. of the Interior, Fish and Wildlife Service. 1959.

2/ U.S. Dept. of the Interior, Fish and Wildlife Service. 1960.

3/ The U.S. Dept. of the Interior 1959 study utilized a factor of 2.25 in the 25 year projection, based on a growth factor of 3.0 and losses due to the construction of C-24. The actual population growth factor from 1955 to 1978 was approximately 6.7. I used this 2.25 figure for consistency in projection of the South Fork, Bridge and Inlet data.

4/ U.S. Dept. of the Interior, Fish and Wildlife Service. 1970. According the Hunting and Fishing survey conducted, the average salt-water fisherman expenditure was $10.77 per anger day.

during the June 1978-June 1979 year. The nine species were snook, croaker, sheepshead, mullet, black drum, weakfish, gafftopsail catfish, gray snapper and Irish pompano. The discharges from the St. Lucie Canal over the survey period amounted to 440,000 acre-feet as compared to the previous 21-year average of 561,000 acre-feet. In addition, 91,000 acre-feet from C-23 and 88,000 acre-feet from C-23A also flowed into the estuary during the survey period.

We propose three theories for the significant changes in catch rates we found in response to the moderate discharges: (1) movement within the estuary, possibly due to the enhanced food supply flushed through with the freshwater; (2) movement to adjacent areas within the estuary that are initially less influenced by the effects of the discharges; and (3) movement to the farthest zone from the discharge sources.

Both snook and mullet moved within the estuary in patterns that would indicate movement in response to food supply. However, snook being carnivorous, exhibited a more instantaneous reaction. Small fishes, including juveniles and forage fishes are often flushed through with the discharges. As a result, it is a well-known fact that snook move to these structures during discharge periods and are more easily caught. Mullet, on the other hand, consume primarily detritus and algae. Their feeding response, evident after prolonged discharges, may be a side-effect of the increased detrital material made available.

Mullet also demonstrated temporary movement into the South Fork in response to North Fork discharges as did gray snapper. Previous studies indicate that a stratified layer of freshwater moves out of the South Fork, into the main estuary, and out the inlet following St. Lucie Canal discharges (Haunert and Startzman 1980). If indeed waterflow from one or the other fork results in minimum mixing with the adjacent fork, then the sheltering effect of the adjacent fork, not only from salinity changes but associated turbulence, is an important consideration in fish movement.

It is evident that there may be a threshold discharge amount beyond which sheltering is no longer effective. For example, gray snapper catch rates increased instantaneously down the South Fork as a result of North Fork discharges. However, as the duration of North Fork discharges lengthened, catch rates for snapper increased in the inlet section. Indications are that the first response of gray snapper may be to move to the South Fork as a result of North Fork discharges, but soon afterwards, as effects are felt in the South Fork as well, movement is toward the inlet section.

Sheepshead, black drum, Irish pompano or mojarra, weakfish, gafftopsail catfish, croaker and eventually gray snapper all showed a tendency for increased catch rates in the inlet section, the farthest zone from the discharge sources. This movement lagged 1-6 weeks behind the discharge. Although several of these species are considered to be salinity limited, they were all affected similarly by the discharges.

An analysis was done to see how the four inflow sources, rain, St. Lucie discharges, C-23 and C-23A discharges, affect the time fishermen spend on the estuary. Short-term effects of the discharge sources on fishing pressure indicate that neither weekly cumulative rainfall nor St. Lucie Canal discharges significantly affect fishing pressure throughout the estuary. On the other hand, increases in North Fork discharges (C-23A) were found to be correlated with increased South Fork usage. However, fishing pressure in both the North Fork and inlet section were negatively affected by C-23 and C-23A freshwater releases.

Comparison of this study with studies done on the North Fork in 1959 and fishermen counts done on the estuary, indicate that less angler days are spent on the St. Lucie now than in the late 1950's. The cause of this loss in angler usage over the past 22 years may be the drop in harvest percentages of the most desirable species, notably snook, croaker, and tarpon. In terms of fishermen's expenditures, the cost of this loss amounts to approximately one million dollars per year.

In conclusion, freshwater discharges by the St. Lucie Canal were found to have significant short-term effects on the catch rates of nine important estuarine species. Essentially what this means to local fishermen is that during discharges species habits are less predictable, and the augmented freshwater releases are causing fish movements. Long-term analyses show an actual drop in angler usage of the estuary in the face of great increases in human populations.

LITERATURE CITED

A list of common and scientific names of fishes from the United States and Canada. Washington, D.C.: American Fisheries Society. Special Publication No. 6, 3rd Edition, 1970.

Gunter, J.; Hall, G. Biological investigations of the St. Lucie Estuary (Fla.) in connection with Lake Okeechobee discharges through the St. Lucie Canal, 1963. Gulf Coast Research Laboratory 1(5): 189-307.

Haunert, Daniel E.; Startzman, J. Some seasonal fisheries trends and effects of a 1,000 cfs freshwater discharge on the fishes and macroinvertebrates in the St. Lucie Estuary, Florida, 1980. South Florida Water Management District, Technical Publication 803; 1980.

U.S. Dept. of the Interior, Fish and Wildlife Service. An interim report on the fish and wildlife resources in relation to the Corps of Engineers plan of development for the St. Lucie Canals, Florida; 1959.

U.S. Dept. of the Interior, Fish and Wildlife Service. A report on the effects of the St. Lucie Canal discharges on the fish and wildlife resources of the St. Lucie River system (A unit of Lake Okeechobee regulation), 1960. Preliminary draft.

U.S. Dept. of the Interior, Fish and Wildlife Service. 1970 National Survey of Fishing and Hunting. Resource Publication No. 95.

EFFECTS OF FRESHWATER RUNOFF ON FISHES OCCUPYING THE FRESHWATER AND ESTUARINE COASTAL WATERSHEDS OF NORTH CAROLINA

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ABSTRACT

Presently 37 freshwater and 77 marine fishes, within 13 freshwater and 38 marine families, respectively, are known to inhabit the oligohaline or euryhaline "freshwater" estuaries of coastal North Carolina for prolonged periods. Most species are typical primary, secondary, diadromous, complementary or sporadic fishes, as defined by Myers (1938; 1949a,b; 1951). Eighteen of the freshwater and 37 of the marine fishes noted are new additions to the lists compiled by Schwartz (1964) and Gunter (1942, 1956) of known fishes which occur in low salinity fresh waters. The extent of the euryhaline zone created by seasonal or sudden runoff conditions, is described for each of the major coastal watersheds of North Carolina. Maximum or minimum salinity occurrence levels are noted for each species frequenting the area. Comments similar to Gunter *et al*. (1974) are presented on length of survival in low saline water situations and/or responses to other environmental variables, in relation to fish size.

INTRODUCTION

Fishes are usually categorized as primary, secondary, peripheral freshwater or marine, yet we know that there are anadromous, catadromous, diadromous, amphidromous, potamodromous, oceanodromous, vicarious, complementary or sporadic (Myers 1938; 1949a, b; 1951) fishes that pass into or out of fresh or marine regimes (Hoar and Randall 1979). Faunal fish surveys, however, are usually stilted to sampling either in fresh or marine habitats (i.e., Carr and Goin 1955; Douglas 1974; Livingston *et al*. 1976, 1977). Occasionally, there have been efforts to study the "salting out" effects where fresh waters mix with marine waters (i.e., Chesapeake Research Consortium 1976; Lauff 1967; Wiley 1978). More importantly almost no prolonged study has been aimed at that unstable area where fresh waters meet estuarine waters, the area that was estuarine and which suddenly is transformed into a freshwater habitat by increased freshwater runoff or to what happens to the fish faunas of either regimes when subjected to sporadic or rapid freshwater intrusions.

DEFINITIONS AND TERMINOLOGIES

While some would prefer to call that area located between fresh and saline waters, where two waters dilute each other, an estuary (Hedgpeth 1951; McHugh 1966; Lauf 1967; Pritchard 1967a), others designate it as brackish waters (Dahl 1956; Kinne 1964; Caspers 1967). To others the battle rages on in the search for an adequate terminology that defines the freshwater-saline interzone (McHugh 1967; Abbott and Dawson 1975; Schubel and Hirschberg 1978). Some even characterize this body of water by inferring it is made up of monotonous or abundant, mainly euryhaline marine fishes (Hedgpeth 1957). I am likewise at a loss when referring to this stratified euryhaline zone or habitat which flood or freshwater runoff waters convert into a purely freshwater habitat (Pritchard 1967a). Is it simply an extension of the freshwater zone or should some new terminology be applied to this temporary zone, habitat, or condition?

The unsettled definition of what is fresh water (Gunter et al. 1974) rages just as that of what is an estuary. For many years fresh waters were defined as those of 0.2 to 0.05 percent (Valikanges 1933; Dahl 1956) even though an international attempt was made to classify fresh water as those of 0-0.5 ppt salinity (Symposium in Classification of Brackish Waters 1958). Kinne (1964, 1967) presented good overviews to the problem. Gunter et al. (1974) and Odum (1953) presented excellent reviews of the physiological and environmental influences on estuarine fishes which can be extended to what happens to a fish which finds itself suddenly "trapped" or subject to a runoff freshwater intrusion area of a stream or river. I will not resolve, herein, the question of whether such fishes should be referred to as euryhaline, oligohaline or some other designation (Gunter 1942, 1956; McHugh 1964; Gunter et al. 1974) but add to the list of known occurrences of fresh water and marine fishes that we know live in such waters, with comments on their sizes, and possibly interacting factors.

METHODS

The fishes encountered in the runoff zone of the major rivers of North Carolina were captured during the past 12 years (1968-1980) by various sized anchored gill nets and 8.0-13.5-m semiballoon otter trawls. Gill net sets were usually for 24 hr and trawl tows were for 0.25 to 0.5 hr duration. Specimens captured by gill net, unless too damaged by crabs or decayed by high summer water temperatures, or otter trawl were preserved in the field in 10 percent formalin for later study and/or inclusion in the fish collection at the Institute of Marine Sciences, Morehead City, North Carolina.

Environmental variables of water temperature, oxygen, current speed, tide state, salinity were recorded by Taylor temperature thermometers (°C), direct reading YSI oxygen (ppm)-temperature probes, and A/O refractometers for salinity in ppt. Fish lengths were recorded as standard lengths unless a total (tonguefish) or fork length (sturgeon) was more representative.

DESCRIPTION OF NORTH CAROLINA

RIVERS AND SOUNDS

Schwartz and Chestnut (1973), Williams et al. (1973), and Williams and Deubler, in part (1968), compiled the seasonal isohalines of the sound and coastal waters of North Carolina. The rivers that empty into the coastal sounds (Figure 1) are most affected in early spring, especially March or April, when runoff (the result of rains or melting snow upstream) is highest. The major watersheds of North Carolina, from north to south, are the Chowan-Roanoke, Albemarle Sound, Pamlico-Pungo River, Neuse River, Bay River, Newport River, White Oak River, New River, and Cape Fear River (Figure 1). These likewise feed into the major sounds of Albemarle-Currituck, Croatan, Roanoke, and Pamlico. Numerous smaller sounds exist south of Pamlico Sound but they are usually short in length or subject to more oceanic influences than freshwater runoff (Figure 1). Most of the major rivers of North Carolina have extensive watersheds and are usually 10m or less deep. The Cape Fear River, in the southern portion of the state, is the largest and is dredge-maintained upstream at 13 to 15m to Wilmington, North Carolina.

Albemarle and Currituck Sounds are typically freshwater habitats during most of the year. Spring freshet runoff of these freshwaters extend 28 km into the low saline 8 ppt to 20 ppt Croatan and Roanoke Sounds thereby carrying fresh waters southward to Oregon Inlet (Figure 1). During the late fall (November) saline waters from Croatan and Roanoke sounds may extend into and along the lower eastern third of Albemarle Sound.

The Pamlico-Pungo rivers are usually saline from near Washington and Winsteadville, North Carolina. Spring or sudden runoffs lower these 10 ppt to 17 ppt waters to 0 ppt for distances of 60 and 15 km respectively.

The short 5 km Bay River is not included in the discussions of this study as it usually does not have a clearly defined freshwater intrusion zone. Instead runoff waters flow out into Pamlico Sound as a layer over the highly saline bottom waters.

The Neuse River is fresh-water to just downstream of Grifton, North Carolina. The affected area of spring freshwater intrusion moves 0 ppt salinity waters 35 km to the junction of the Neuse River with Pamlico Sound. Surface waters of Pamlico Sound, during hurricane or other heavy rains, have been found fresh the entire extent from west to east and often pour out the inlets in the outer banks as a definite visible water mass (Schwartz 1973). However, 7 ppt to 32 ppt salinities usually prevail within Palmico Sound (Schwartz and Chestnut 1973).

The Newport River is a short compressed estuary of 12 km and is subject to large saline intrusions from the nearby Atlantic Ocean (Hyle 1976). The freshwater runoff zone has extended downstream for 4 to 5 km from its confluence with the estuary near the "Crossrocks."

The White Oak River is a long shallow river subject to high saline intrusions from the nearby ocean in its lower courses. During runoff the vertical freshwater face has been moved downstream 15 km to Stella, North Carolina.

The New River is another saline intrusion-influenced river, yet the runoff zone is often extended southeast of Jacksonville, North Carolina for 12 km.

The Cape Fear River is a swift river which, in its lower 30 km, is subject to 2-m tidal influences. Cape Fear experiences the highest

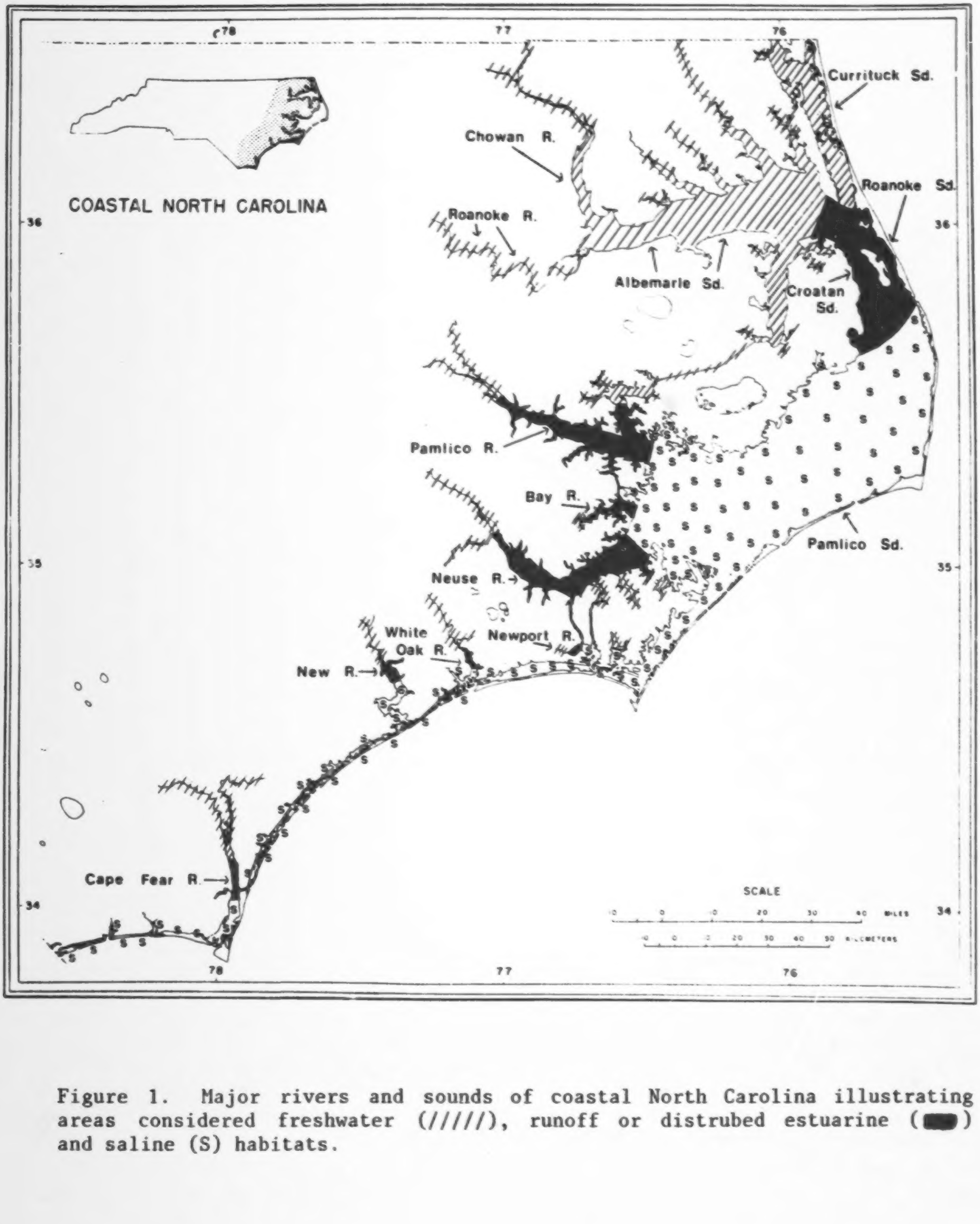
78
77
76
COASTAL NORTH CAROLINA
Currituck Sd.
Chowan R.
Roanoke Sd.
36
Roanoke R.
Albemarle Sd.
Croatan Sd.
Pamlico R.
Bay R.
Pamlico Sd.
35
Neuse R.
White Oak R.
Newport R.
New R.
Cape Fear R.
SCALE
10 0 10 20 30 40 MILES
10 0 10 20 30 40 50 KILOMETERS
34

Figure 1. Major rivers and sounds of coastal North Carolina illustrating areas considered freshwater (/////), runoff or distrubed estuarine (■) and saline (S) habitats.

runoff of any watershed, 257,929 to 7,264,664 liters/mo and flows of 66 cm/sec have been recorded (Schwartz et al. 1979a, b). However, that area from Campbell Island, 9 km south of Wilmington, North Carolina, to the man-made cut, "Snows Cut," 15 km further downstream is often subjected to periodic freshwater runoff which produces 0 ppt recordings throughout the 13-m deep waters for periods of 6 to 8 weeks (Schwartz et al. 1979a, b).

DISCUSSION

Hoagman and Wilson (1976), Lowe-McConnell (1975), and Schubel et al. (1976), have documented the natural or induced downstream shift of the oblique or vertical freshwater-saline interface of a coastal stream or river following a rain or hurricane. Others (Chesapeake Res. Cons. 1976) have noted the resiliency of these saline-depressed waters as they return to nearly "normal" states within short or long intervals but have not resolved the question--is this disturbed zone a truly freshwater or some sort of hybrid habitat? Likewise, what happens to the freshwater and marine fishes that are momentarily "trapped" within these temporary and rapidly chemically changing waters (Aller 1978; McHugh 1960)? It is to this unstable and temporary no man's land between fresh and saline waters that I now address this report.

RESULTS

To date only Schwartz (1964) has compiled a list of freshwater fishes that are known from runoff freshwater-euryhaline waters. Gunter (1942, 1956) compiled a similar list for 150 marine fishes known from euryhaline waters. Otherwise the sporadic occurrence of a species is usually treated as a brief note that one or more characteristically freshwater or marine fish was encountered in a freshwater, euryhaline, or marine habitat or vice versa (Rohde et al. 1979).

I now add to Schwartz's 28 (1964) and Gunter's 150 (1942, 1956) species lists of fishes that 37 freshwater (Table 1) and 77 marine (Table 2) fishes, within 13 freshwater and 38 marine families respectively, are known to frequent or live in "freshwater" runoff habitats within the major tributaries of North Carolina (Figure 1). Seven of the freshwater species were found in waters that were or reverted to 22 ppt to 31 ppt salinities following runoff. These included the longnose gar (*Lepisosteus osseus*), gizzard shad (*Dorosoma cepedianum*), golden shiner (*Notemigonus chrysoleucus*), white catfish (*Ictalurus catus*), brown bullhead (*Ictalarus nebulosus*), mosquitofish (*Gambusia affinis*, and flier (*Centrarchus macropterus*). Of these Schwartz (1964) had, elsewhere, collected the gar from 23.4 ppt, gizzard shad 22.6 ppt, golden shiner 14.4 ppt, and white catfish 14.5 ppt (Schwartz and Kendall 1968) waters. Twenty-five of the 37 freshwater fishes were found in higher salinities, in North Carolina, than previously noted by Schwartz (1964). In some cases, such as the gizzard shad, mosquitofish, bluegill, and pumpkinseed, their occurrences were recorded as abundant. Most of the freshwater fishes (20) were rare captures in the runoff zone, which reverted to 1 ppt to 27 ppt salinities. Thirteen species were common to zones that had been 1ppt to 31 ppt salinity Nine centrarchids and eight cyprinids were fishes that frequented the runoff disturbed areas for prolonged periods of 6 to 8 weeks prior to their retreat upstream into "pure" freshwater habitats. No trend was evident of increased number or kind of fish inhabiting the runoff area.

TABLE 1. List of 37 freshwater fishes, within 13 families, known to occur in previously considered estuarine waters of North Carolina when subjected to periodic flood water runoff.

Common-Scientific Name	Watershed								Max. Sal.	Prev. Lit.	New Sal. High	Status
	Cho	Alb	Pam	N	Np	WO	Ne	CF				
Gars - Lepisosteidae												
Longnose gar - Lepisosteus osseus	X	X	X	X	X	X	X	X	31	S	*	C
Bowfins - Amiidae												
Bowfin - Amia calva	X	X	X	-	-	-	-	X	5			R
Herrings - Clupeidae												
Gizzard shad - Dorosoma cepedianum	X	X	-	-	-	-	-	X	30	S	*	Abd
Mudminnows - Umbridae												
Eastern mudminnow - Umbra pygmaea	X	X	-	-	-	-	-	-	12	S	*	R
Pikes - Esocidae												
Chain pickerel - Esox niger	X	X	-	-	-	-	-	-	5	S	*	C
Minnows - Cyprinidae												
Carp - Cyprinus carpio	X	X	-	-	-	0	0	X	1	S		C
Silvery minnow - Hybognathus nuchalis	X	X	-	-	0	0	0	0	6	S	*	R
Golden shiner - Notemigonus crysoleucas	X	X	X	-	-	-	-	X	27	S		C
Ironcolor shiner - Notropis chalybaeus	-	-	-	-	-	0	-	-	6			R
Dusky shiner - Notropis cummingsae	0	0	-	-	0	-	-	X	2		*	R
Spottail shiner - Notropis hudsonius	X	X	-	-	0	0	0	-	4	S	*	R
Coastal shiner - Notropis petersoni	0	0	0	0	0	0	-	X	3		*	R
Swallowtail shiner - Notropis procne	X	-	0	0	0	0	0	0	1		*	R
Suckers - Catostomidae												
Creek chubsucker - Erimyzon oblongus	X	-	X	-	-	-	-	-	9	S	*	R
Shorthead redhorse - Moxostoma macrolepidotum	X	X	-	-	0	0	0	-	8	S	*	R
Freshwater catfish - Ictaluridae												
White catfish - Ictalurus catus	X	X	X	X	-	-	-	X	27	S	*	C
Blue catfish - Ictalurus furcatus	0	0	0	0	0	0	0	X	1		*	R
Yellow bullhead - Ictalurus natalis	X	X	-	-	-	-	-	-	5		*	R
Brown bullhead - Ictalurus nebulosus	-	-	X	-	-	-	-	X	27	S		R
Tadpole madtom - Noturus gyrinus	X	X	-	-	-	-	-	-	5		*	R
Margined madtom - Noturus insignis	X	0	-	-	-	X	-	-	5		*	R
Cavefishes - Amblyopsidae												
Swampfish - Chologaster cornuta	X	-	-	-	-	-	0	-	5		*	R
Pirate Perch - Aphredoderidae												
Pirate perch - Aphredoderus sayanus	X	X	X	-	X	-	-	X	5		*	R
Livebearers - Poeciliidae												
Mosquitofish - Gambusia affinis	X	X	X	X	X	-	-	X	22	S		Abd
Sunfishes - Centrarchidae												
Flier - Centrarchus macropterus	X	X	X	X	-	-	-	X	24		*	C
Banded pygmy sunfish - Elassoma zonatum	0	0	-	-	X	0	0	-	2		*	R
Bluespotted sunfish - Enneacanthus gloriosus	X	X	X	-	-	-	-	-	5	S		C
Redbreast sunfish - Lepomis auritus	X	X	-	-	-	-	-	-	7		*	C
Pumpkinseed - Lepomis gibbosus	X	X	X	X	-	X	-	-	15	S		Abd
Warmouth - Lepomis gulosus	X	X	X	-	-	-	-	-	7		*	R
Bluegill - Lepomis macrochirus	X	X	X	-	X	X	-	X	9	S		Abd
Largemouth bass - Micropterus salmoides	X	X	X	-	-	X	-	X	5	S		C
Black crappie - Pomoxis nigromaculatus	X	-	-	-	-	0	0	X	1.3		*	R
Perches - Percidae												
Swamp darter - Etheostoma fusiforme	X	-	X	-	-	-	0	X	5	S		C
Tessellated darter - Etheostoma olmstedi	X	X	-	-	0	-	-	X	6		*	C
Sawcheek darter - Etheostoma serriferum	-	-	-	X	-	-	-	-	8		*	C
Yellow perch - Perca flavescens	X	X	X	-	0	-	-	X	5	S		C

0 = not known from watershed
- = known in watershed but not collected in disturbed portion
X = known from disturbed portion of watershed
Cho = Chowan River
Alb = Albemarle Sound, includes Currituck, Croatan and Roanoke Sounds
Pam = Pamlico River and Sound
N = Neuse River
Np = Newport River
WO = White Oak River
Ne = New River
CF = Cape Fear River
Max. Sal. = Maximum salinity in which specimen was captured
Prev. Lit. = Previous literature citation of either G (Gunter) or S (Schwartz)
* = established new high for recorded salinity observation
C = Common
R = Rare
Abd = abundant, yg = young
S = Schwartz 1964
G = Gunter 1942, 1956

TABLE 2. List of 77 marine fishes, within 38 families, known to occur in previously considered estuarine waters of North Carolina which tolerate 0 ppt salinities for prolonged periods when the estuary is subjected to periodic flood water runoff. (See Table 1 for explanation of symbols.)

Common-Scientific Name	Watershed								Prev. Lit.	Status
	Cho	Alb	Pam	N	Np	WO	Nw	CF		
Lampreys - Petromyzontidae										
Sea lamprey - *Petromyzon marinus*	-	X	-	X	-	-	-	X	G	R
Requiem Sharks - Carcharhinidae										
Atlantic sharpnose shark - *Rhizoprionodon terraenovae*	0	0	-	-	X	X	X	X	G	C
Skates - Rajidae										
Clearnose skate - *Raja eglanteria*	0	0	0	-	X	X	X	X		C
Stingrays - Dasyatidae										
Southern stingray - *Dasyatis americana*	0	0	X	X	X	X	X	X		R
Atlantic stingray - *Dasyatis sabina*	0	0	0	0	X	X	X	X	G	C
Sturgeons - Acipenseridae										
Atlantic sturgeon - *Acipenser oxyrhynchus*	X	X	X	X	X	X	X	X	G	Abd
Freshwater Eels - Anguillidae										
American eel - *Anguilla rostrata*	X	X	X	X	X	X	X	X	G	Abd
Conger Eels - Congridae										
Conger eel - *Conger oceanicus*	0	0	-	-	X	X	X	X		C
Snake Eels - Ophichthidae										
Shrimp eel - *Ophichthus gomesi*	0	0	-	-	X	X	X	X		C
Herrings - Clupeidae										
Atlantic menhaden - *Brevoortia tyrannus*	X	X	X	X	X	X	X	X	G	Abd
Blueback herring - *Alosa aestivalis*	X	X	X	X	X	X	X	X	G	Abd
Hickory shad - *Alosa mediocris*	X	X	X	X	X	X	X	X	G	Abd
Alewife - *Alosa pseudoharengus*	X	X	X	X	X	X	X	X	G	Abd
American shad - *Alosa sapidissima*	X	X	X	X	X	X	X	X	G	Abd
Threadfin shad - *Dorosoma petenense*	0	0	X	X	-	-	-	X		Abd
Atlantic thread herring - *Opisthonema oglinum*	-	-	X	X	X	-	-	X		C
Anchovies - Engraulidae										
Striped anchovy - *Anchoa hepsetus*	-	X	X	X	X	-	-	X		C
Bay anchovy - *Anchoa mitchilli*	X	X	X	X	X	X	X	X	G	Abd
Toadfishes - Batrachoididae										
Oyster toadfish - *Opsanus tau*	0	0	X	X	X	X	X	X		C
Clingfishes - Gobiesocidae										
Skilletfish - *Gobiesox strumosus*	0	0	-	-	X	X	X	X		C
Codfishes - Gadidae										
Spotted hake - *Urophycis regius*	0	0	X	X	X	X	X	X		C
Cusk-eels - Ophidiidae										
Crested cusk-eel - *Ophidion welshi*	0	0	0	0	-	-	-	X		R
Needlefishes - Belonidae										
Atlantic needlefish - *Strongylura marina*	X	X	X	X	X	X	X	X	G	C
Killifishes - Cyprinodontidae										
Sheepshead minnow - *Cyprinodon variegatus*	0	0	X	X	X	X	-	X	G	C
Banded killifish - *Fundulus diaphanus*	X	X	X	-	X	0	X	-		C
Mummichog - *Fundulus heteroclitus*	0	0	X	-	X	X	X	X	G	C
Striped killifish - *Fundulus majalis*	0	0	-	-	-	-	-	X		C
Rainwater killifish - *Lucania parva*	0	0	X	X	0	0	0	0	G	R
Silversides - Atherinidae										
Rough silverside - *Membras martinica*	0	0	X	X	-	0	0	X	G	C
Tidewater silverside - *Menidia beryllina*	X	X	X	X	X	X	X	X	G	Abd
Atlantic silverside - *Menidia menidia*	0	X	-	X	X	X	X	X	G	Abd
Pipefishes - Syngnathidae										
Lined seahorse - *Hippocampus erectus*	0	0	X	X	X	X	X	X		C
Northern pipefish - *Syngnathus fuscus*	0	0	-	-	-	-	-	X		C
Chain pipefish - *Syngnathus louisianae*	0	0	-	-	-	-	-	X		C
Snooks - Centropomidae										
Snook - *Centropomus undecimalis*	0	0	-	0	0	0	0	X		R
Temperate Basses - Percichthyidae										
White perch - *Morone americana*	X	X	X	X	-	-	-	X	G	Abd
Striped bass - *Morone saxatilis*	X	X	X	X	X	X	X	X	G	Abd
Sea Basses - Serranidae										
Black sea bass - *Centropristis striata*	0	0	-	-	X	X	X	X		R (yg)
Bluefishes - Pomatomidae										
Bluefish - *Pomatomus saltatrix*	0	-	X	X	X	X	X	X		Abd (yg)
Jacks - Carangidae										
Crevalle jack - *Caranx hippos*	0	0	-	-	X	X	X	X	G	C
Atlantic bumper - *Chloroscombrus chrysurus*	0	0	-	-	X	X	X	X		R
Snappers - Lutjanidae										
Gray snapper - *Lutjanus griseus*	0	X	X	X	X	X	X	X	G	R
Mojarras - Gerreidae										
Spotfin mojarra - *Eucinostomus argenteus*	0	0	-	-	X	X	X	X		R
Grunts - Pomadasyidae										
Pigfish - *Orthopristis chrysoptera*	0	0	X	X	X	X	X	X		C
Porgies - Sparidae										
Sheepshead - *Archosargus probatocephalus*	0	0	-	-	X	-	X	X	G	C (yg)
Pinfish - *Lagodon rhomboides*	0	0	X	X	X	X	X	X	G	Abd
Drums - Sciaenidae										
Silver perch - *Bairdiella chrysura*	0	0	X	X	X	X	X	X		C
Spotted seatrout - *Cynoscion nebulosus*	0	0	X	X	X	X	X	X		C
Weakfish - *Cynoscion regalis*	0	0	X	X	X	X	X	X	G	C
Spot - *Leiostomus xanthurus*	0	0	X	X	X	X	X	X	G	C
Southern kingfish - *Menticirrhus americanus*	0	0	-	-	X	X	X	X		C
Atlantic croaker - *Micropogonias undulatus*	0	0	X	X	X	X	X	X	G	C
Black drum - *Pogonias cromis*	0	0	X	X	X	X	X	X	G	Abd (yg)
Red drum - *Sciaenops ocellata*	0	0	X	X	X	X	X	X	G	C
Star drum - *Stellifer lanceolatus*	0	X	X	X	X	-	-	X		C
Mullets - Mugilidae										
Striped mullet - *Mugil cephalus*	X	X	X	X	X	X	X	X	G	Abd
White mullet - *Mugil curema*	0	0	X	X	X	X	X	X	G	Abd
Stargazers - Uranoscopidae										
Southern stargazer - *Astroscopus y-graecum*	0	0	-	-	X	X	X	X		R
Combtooth blennies - Blenniidae										
Crested blenny - *Hypleurochilus geminatus*	0	0	-	X	X	X	X	X		C
Freckled blenny - *Hypsoblennius ionthas*	0	0	0	0	0	0	0	X		R
Sleepers - Eleotridae										
Fat sleeper - *Dormitator maculatus*	0	0	0	0	0	-	0	X	G	R
Gobies - Gobiidae										
Lyre goby - *Evorthodus lyricus*	0	0	0	0	0	0	0	X	G	R
Darter goby - *Gobionellus boleosoma*	0	0	0	0	X	-	-	X	G	R
Sharptail goby - *Gobionellus hastatus*	0	0	-	-	X	X	X	X		C
Freshwater goby - *Gobionellus shufeldti*	0	0	-	-	X	-	-	X	G	R
Naked goby - *Gobiosoma bosci*	0	0	-	-	X	X	X	X	G	C
Butterfishes - Stromateidae										
Harvestfish - *Peprilus alepidotus*	0	0	X	X	X	X	X	X		C
Searobins - Triglidae										
Bighead searobin - *Prionotus tribulus*	0	X	X	X	X	X	X	X		C
Lefteye flounders - Bothidae										
Ocellated flounder - *Ancylopsetta quadrocellata*	0	0	-	X	X	X	X	X		C
Bay whiff - *Citharichthys spilopterus*	0	0	-	X	X	X	X	X	G	C
Fringed flounder - *Etropus crossotus*	0	0	-	-	-	-	-	X		C
Summer flounder - *Paralichthys dentatus*	X	0	X	X	X	X	X	X	G	Abd
Southern flounder - *Paralichthys lethostigma*	0	0	X	X	X	X	X	X	G	C
Broad flounder - *Paralichthys squamilentus*	0	0	X	X	X	X	X	X		R
Windowpane - *Scophthalmus aquosus*	0	0	X	X	X	X	X	X		Abd
Soles - Soleidae										
Hogchoker - *Trinectes maculatus*	X	X	X	X	X	X	X	X	G	Abd
Tonguefishes - Cynoglossidae										
Blackcheek tonguefish - *Symphurus plagiusa*	0	0	-	X	X	X	X	X		Abd (yg)

Of the marine fishes found in freshwater runoff areas, all 77 listed (Table 2) were found in 0 ppt salinity waters for extended periods as long as six weeks. As expected, anadromous, catadromous, and diadromous fishes such as sturgeon, herrings, shad, and eels also were abundant in the 0 ppt runoff water zones. Other abundant fishes within the runoff area were the bay anchovy; tidewater and Atlantic silversides; white perch; striped bass; bluefish (young); sheepshead (yg); pinfish (yg); black drum (yg); striped and white mullet; summer, southern, and windowpane flounders; hogchokers; and blackcheek tonguefish (Table 2). Thirty-seven of the 77 marine or euryhaline fishes were common to the various disturbed runoff watersheds of the state while only 15 were rare occurrences within these waters. Herrings (9 species), drums (7), and flounders (7) were the dominant groups of fishes captured in the runoff zones. Thirty-five of the 77 marine fishes occurred in 0 ppt waters and had not been reported previously by Gunter (1942, 1956).

Of the fishes encountered within the runoff zone, most were small juvenile or one-year-old age class individuals. Some species, such as the drums and flounders, were known to migrate to low salinity nursery waters and hence their presence in the runoff zone could be accounted for by such behaviors (Marshall 1976; Weinstein 1979, 1980). None exhibited external signs of stress or emaciation as a result of their living in or encounter with the runoff zone.

The presence or absence of several species within a watershed or the runoff area was also a function of zoogeography (Jenkins et al. 1972; Rohde et al. 1979) rather than runoff or environment, as North Carolina lies at the junctures of many coastal north and south ranging species. Like Gunter et al. (1974) presence or absence of a freshwater or marine fish in a runoff area was dependent on many other factors, expecially water temperature and oxygen content.

Water temperatures and oxygen levels, in most areas, of North Carolina were not limiting factors as most runoff occurred during months when water temperatures were low and contained high levels of oxygen (see Schwartz 1973; Schwartz et al. 1979a, b, six-year study of Cape Fear River). Whether the varying chemical content of the various watersheds (Geraghty et al. 1973) played a role in the enhancement or demise of a species that was subjected to the sudden runoff waters remains unknown.

Likewise nutrient change, as a result of runoff, is poorly known for North Carolina waters, the exception being the Neuse River where Hobbie and Smith (1975) noted the effects of runoff on various environmental parameters.

Nichols (1977), Schubel and Hirschberg (1978), and many others have documented the enormous sediment changes that can occur in a body of water which has been subjected to river floods. Giese et al. (1979), reviewing the hydrology of the major estuaries of North Carolina, noted the effects of sediment "salting out" following freshwater inflow and calculated the number of days one could expect upriver portions of major rivers to be drastically affected by this phenomenon. Edgwald (1972) and Griffin and Ingram (1955) reviewed the sediments of coastal Pamlico and Neuse Rivers as a result of runoff. In turn, these sediments most likely caused changes in bottom chemical conditions (Aller 1978) or bottom macroinvertebrates faunas (Schwartz et al. 1979a, b) on which the runoff zone fishes fed (Schwartz et al. 1980). Yet little information exists, in North Carolina, on the fate of freshwater fishes, their transport into or within the runoff area, and how they are affected by sediments (Custer and Ingram 1974).

CONCLUSIONS AND RECOMMENDATIONS

Many aspects remain unresolved in relation to fishes and the runoff zone and will provide research for the future. Thus, we must take the next step and test various species, under a variety of sudden or runoff conditions (Livingston et al. 1976), to determine why some cyprinids, centrarchids, clupeids, sciaenids, and bothids can exist in the unstable environment caused by freshwater runoff while others cannot. Only then will we begin to understand a runoff habitat, a fish's needs, and how we can best assure its survival in these rapidly changing runoff waters and habitats.

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LITERATURE CITED

Abbott, D.; Dawson, C.E.; Oppenheimer; C.H. Physical, chemical, and biological characteristics of estuaries. Water and pollution handbook. New York: Marcel Dekker Inc., N.Y. Vol. 1.; 1971. 51-140.

Aller, R.C. The effects of animal-sediment interactions on geochemical processes near the sediment-water interface. Wiley, M. L. ed. Estuarine interactions. New York, NY: Academic Press; 1978: 157-172.

Carr, A.; Goin, C. J. Reptiles, amphibians and freshwater fishes of Florida. Gainesville: Univ. Fla. Press; 1955: 341p.

Caspers, H. Estuaries: Analysis of definitions and biological considerations. Lauff, G. H. ed. Estuaries. Washington, DC: Amer. Assoc. Adv. Sci., Pub. 83; 1967.

Chesapeake Research Consortium. The effects of tropical storm Agnes on the Chesapeake Bay Estuarine System. Ches. Res. Consort. Publ. 54, Baltimore, MD: Johns Hopkins Univ. Press; 1976.

Custer, E.S., Jr.; Ingram; R.L. Influence of sedimentary processes on grain size distribution curves of bottom sediments in the sounds and estuaries of North Carolina. Univ. No. Carolina Sea Grant Publ. UNC-SG-74-13; 1974. 88p.

Dahl, E. Ecological sedentary boundaries of Poikilohaline water. Oikos 7:1-23; 1956.

Douglas, N.H. Freshwater fishes of Louisiana. Baton Rouge, LA: Claitor's Publ. Div.; 1974.

Edgwald, J.K. Coagulation in estuaries. Univ. No. Carolina Sea Grant Publ. UNC-SG-72-06; 1972: 204p.

Geraghty, J.J.; Miller, D.W.; von der Leeden, F.; Troise, F.L. Water atlas of the United States. Washington, New York: Water Info. Center Publ. Port 1973; 119 p.

Giese, G.L.; Wilder, H.B.; Parker, G.C., Jr. Hydrology of major estuaries and sounds in North Carolina. U.S. Geol. Surv. Water Res. Investig. 79-46, 1979; 175p.

Griffin, G.M.; Ingram, R.L. Clay minerals of the Neuse River Estuary. Sediment. Petrol. 25(3): 194-200; 1955.

Gunter, G. A list of the fishes of the mainland of North and Middle America recorded from both freshwater and sea water. Amer. Midl. Nat. 28(2):305-326; 1942.

Gunter, G. A revised list of euryhaline fishes of North and Middle America. Amer. Midl. Nat. 56 (2):345-354; 1956.

Gunter, G.; Ballard, B. S.; Venkataraniah, A. A review of salinity problems of organisms in Central States Coastal area subject to the effects of engineering works. Gulf Res. Rep.4(3): 380-475; 1974.

Hedgpeth, J.W. The classification of estuarine and brackish waters and the hydrographic limits. Rep. 11 Nat. Res. Comm. 1951: 49-56.

Hedgpeth, J. W. Estuaries and lagoons II. Biological aspects. Hedgpeth, J. W. ed. Treatise on marine ecology and paleocology. Vol. 1, Hedgpeth, J. W. ed. Mem. 67 Geol. Soc. Amer. Vol. 1; 1957: 643-729.

Hoagman, W.J.; Wilson, W.L. The effects of tropical storm Agnes on fishes in the James, York, and Rappahannock Rivers of Virginia, The effects of tropical storm Agnes on the Chesapeake Bay Estuarine System. Chesapeake Res. Consort. Inc. Publ. 54; 1976: 464-477.

Hobbie, J.E.; Smith, N.W. Nutrients in the Neuse River Estuary. Univ. No. Carolina Sea Grant Publ. UNC-SG-75-21; 1975: 183p.

Hoar, W.S.; Randall, D.J. eds. Fish physiology. VIII. Bioenergetics and growth. New York: Academic Press, 1979. 786p.

Hyle, A.K., II. Fishes of the Newport River Estuary, North Carolina, their composition, seasonality, and community structure. Chapel Hill, N.C.: Univ. No. Carolina; 1976: 192p.

Jenkins, R. E.; Lachner, E. A.; Schwartz, F.J. Fishes of the central Appalachian drainages: Their distribution and dispersal, Holt, P. C. ed. The distributional history of the Southern Appalachians Pt. III Vertebrates. Blacksburg, Va.; 1972: 43-117.

Kinne, O. The effects of temperature and salinity on marine and brackish water animals. II. Salinity and temperature salinity combinations. Oceanogr. Mar. Biol. Annu. Rev. 2: 281-399; 1964.

Kinne, O. Physiology of estuarine organisms with special reference on salinity and temperatures. General aspects. Amer. Assoc. Adv. Sci. Publ. 83:525-540; 1967.

Lauff, G.H. editor. Estuaries. Amer. Assoc. Adv. Sci. Publ. 83, 1967. 757p.

Livingston, R. J.; Cripe, C. R.; Laughlin, R.A.; Lewis, F.G., III. Avoidance responses of estuarine organisms to storm water runoff and pulp mill effluents, Estuarine processes, Vol. 1. New York: Academic Press, Inc., 1976: 313-331.

Livingston, R. J.; Kobylinski, G. J.; Lewis, F.G., III; Sheridan, P.F. Long-term fluctuation of epibenthic fish and invertebrate populations in Apalachicola Bay, Florida. Fish. Bull. 74(2):311-322; 1976.

Livingston, R. J.; Sheridan, P. S.; McLane, B. G.; Lewis, F. G.,III; Kobylinski, G. J. The biota of the Apalachicola Bay system: Functional relationship, Proceedings of a conference on the Apalachicola drainage system. Fla. Mar. Res. Publ. 26; 1977: 75-100.

Lowe-McConnell, R.H. Fish communities in tropical freshwater. New York: Longman. 1975: 337p.

Marshall, H.L. Effects of mosquito control ditching on Juncus marshes and utilization of mosquito control ditches by estuarine fishes and invertebrates. Chapel Hill, N.C.: Univ. No. Carolina, 1976. 294p. Dissertation.

McHugh, J.L. The pound-net fishing in Va. Pt. 2. Species composition of landings reported as menhaden. Comm. Fish. Rev. 22 (2):1-16; 1960.

McHugh, J. L. Management of estuarine fisheries, Smith, R. F.; Swartz, A. H.; Massman, W. H. eds. A symposium on estuarine fisheries. Washington, D.C: Amer. Fish. Soc. Spec. Publ. 3. 1966: 133-154.

McHugh, J. L. Estuarine nekton. Lauff, G. A. ed. Estuaries. Washington, DC: Amer. Assoc. Adv. Sci. Publ. 83; 1967.

Myers, G. S. Freshwater fishes and West Indian Zoogeography. Annu. Rept. Smiths. Inst. Publ. 3451: 339-364 for 1937; 1938.

Myers, G. S. Use of anadromous, catadromous and allied terms for designating fishes. Copeia 1949 (2):89-96; 1949a.

Myers, G. S. Salt-tolerance of freshwater fish groups in relation to zoogeographical problems. Bidjr. Dierkande (Leiden) 27:315-322; 1949b.

Myers, G. S. Freshwater fishes and East Indian Zoogeography. Stanford Icthyol. Bull. 4(1):11-21; 1951.

Nichols, M.M. Response and recovery of an estuary following a river flood. J. Sediment. Petrol. 47 (3):1171-1186; 1977.

Odum, H.T. Factors controlling marine invasion into Florida freshwaters. Bull. Mar. Sci. Gulf. Caribb. 3:134-156; 1953.

Pritchard, N.W. What is an estuary: physical viewpoint. Lauff, G.H., ed. Estuaries. Washington DC: Amer. Assoc. Adv. Sci. Publ. 83; 1967a.

Pritchard, N. W. Observations of circulation in Coastal Plain estuaries. Lauff, G.H. ed. Estuaries. Washington, DC: Amer. Assoc. Adv. Sci. Publ. 83; 1967b; 37-44.

Rohde, F.C.; Burgess, G.H.; Link, G.W. Jr. Freshwater fishes of Croatan National Forest, North Carolina, with comments on the zoogeography of coastal plain fishes. Brimleyana 2: 97-118; 1979.

Schubel, J.R.; Carter, H.H.; Cronin, W.B. Effects of Agnes on the distribution of salinity along the main axis of the bay and in contiguous shelf waters. Effects of tropical storm Agnes on the Chesapeake Bay estuarine system. Chesapeake Res. Consort. Publ. 54; 1976: 33-65.

Schubel, J.R.; Hirschberg, D.J. Estuarine graveyards,climate change, and the importance of the estuarine environment. Wiley, M. L. ed. Estuarine interactions. New York: Academic Press; 1978: 285-303.

Schwartz, F.J. Natural salinity tolerances of some freshwater fishes. Underwat. Nat. 2(2): 13-15; 1964.

Schwartz, F. J. Biological and environmental assessment of four navigation improvement areas to Croatan, Roanoke, and Pamlico Sounds, North Carolina. Wilmington, DL: Rept. U.S. Corps Engineers. DACW 54-72-C-0047; 1973: 75p.

Schwartz, F.J.; Chestnut, A.F. Hydrographic atlas of North Carolina estuarine and sound waters, 1972. UNC-SG-73-12 Sea Grant Publ.; 1973: 132p.

Schwartz, F. J. Kendall, A. Lethal temperatures and salinity tolerances for white catfish, for white catfish, *Ictalurus catus*, from the Patuxent River, Maryland. Chesapeake Sci. 9(2): 103-108; 1968.

Schwartz, F.J.; Morgan, S.; McAdams, M.; Sandoy, K.; Mason, D. Food analyses of selected fishes captured in Cape Fear estuary and adjacent Atlantic Ocean, North Carolina, 1973-1978. Carolina Power Light Co. Pts. 1, 2, 3, Morehead City, NC: Inst. Mar. Sci. 1980; 1100p.

Schwartz, F. J.; Perschbacher, P.; McAdams, M.; Davidson, L.; Sandoy, K.; Simpson, C.; Duncan, J.; Mason, D. A summary report 1973-1977. An ecological study of fishes and invertebrate macrofauna utilizing the Cape Fear River estuary, Carolina Beach Inlet, and adjacent Atlantic Ocean. Carolina Power Light Co. Morehead City, NC: Inst. Mar. Sci. XIV: 1979a: 571p.

Schwartz, F. J.; Perschbacher, P.; McAdams, M.; Simpson, C.; Sandoy, K.; Duncan, J.; Tate, J.; Mason, D. An ecological study of fishes and invertebrate macrofauna utilizing the Cape Fear River estuary, Carolina Beach Inlet, and adjacent Atlantic Ocean. Annu. Rept. for 1978. Carolina Power Light Co. Morehead City, N.C.: Inst. Mar. Sci. XV; 1979b: 326p.

Symposium on the Classification of Brackish Waters. Venis 8-14 April. Centro Naz. Studi Talassograf. Consiglio. Naz. Richerche XI; Suppl.; 1958: 5-248.

Valikanges, I. Uber die biologie der Ostee als Brakwassergebiet. Verh. Int. Ver. Theor. Angew. Limnolog. 6; 1933.

Weinstein, M. P. Shallow marsh habitats as primary nurseries for fishes and shellfish, Cape Fear River North Carolina. Fish. Bull. 77(2):339-357; 1979.

Weinstein, M. P.; Weiss, S. L.; Hodson, R. G.; Gerry, L. R. Retention of three taxa of post larvae fishes in an intensively flushed tidal estuary, Cape Fear River, North Carolina. Fish. Bull. 78(2): 419-436; 1980.

Wiley, M. L. ed. Estuarine Interactions. New York: Academic Press, 1978. 603p.

Williams, A.B.; Deubler, E.E., Jr. A ten-year study of meroplankton in North Carolina Estuaries. Assessment of Environmental Factors and sampling success among Bothid flounders and Penaeid shrimps. Chesapeake Sci. 9(1):27-41; 1968.

Williams, A. B.; Posner, G.S.; Woods, W. J.; Deubler, E. E., Jr. A hydrographic atlas of larger North Carolina Sounds. Univ. No. Carolina Sea Grant Publ. UNC-SG-73-02, 1973; 129p.

CHAPTER 4

FLOOD PLAINS AND ESTUARINE PRODUCTIVITY: ENERGY TRANSPORT, FRESHWATER RUNOFF, AND BIOLOGICAL RESPONSE

VARIATION IN FRESHWATER INFLOW AND CHANGES IN A SUBTROPICAL ESTUARINE FISH COMMUNITY

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ABSTRACT

Trawl-susceptible fishes have been sampled for five years in Charlotte Harbor, Florida. During this period, freshwater inflow recorded on the Peace River has varied from the second lowest to near the mean flow for the past 49 years. The 12 most abundant of 43 taxa captured, comprising about 98 percent of the total catch, were used in the detailed analysis with flow. Average seasonal abundance appeared to be inversely related to flow in the wet season and directly related to flow in the dry season. Strong correlations exist for flow in June and the average abundance for June through September, and also for December-January flows and the average abundance for December through May. Apparent cycles of flow with an average period of six years occur in each season. The wet season of 1977 may represent a minimum point in the wet season cycles. A predicted astronomic tidal effect with a period of 8.86 years reached a minimum in 1977. Relative abundance during the wet season of 1977 was higher than all other wet seasons and may have influenced abundances in the dry season of 1977-1978.

INTRODUCTION

In the Apalachicola drainage basin (Meeter et al., 1979), variability in abundance may be affected by long-term periodic changes of regional (local) climate. The long-term data of Livingston et al. (1978) show a correlation between river flow and fish abundance. This study and others such as Livingston et al. (1976) in the Apalachicola estuarine system provide the nearest (geographic) long-term data on fishes and physical factors to this study.

A study of upper Charlotte Harbor has been underway for five years. Flow characteristics of the Peace River and the subtropical climate of the estuarine area are much different (Taylor, 1974) from those described by Livingston and other workers for the Apalachicola, yet the faunas are similar.

This report briefly addresses the following topics: (1) the relationship of abundance in Charlotte Harbor to Peace River flow; (2) temporal variation in abundance; (3) the relationship of abundance to other factors, such as temperature; and (4) long-term patterns that might exist in river flow and tidal flushing.

A review of Charlotte Harbor characteristics and adjacent bodies of water can be found in Taylor (1974). Information on fishes in the specific area of this study can be found in Finucane (1966), and Wang and Raney (1971). Both studies describe seasonality and general fish community composition. Each study noted that decreasing abundance occurred with decreasing salinity as a result of high flows. Wang and Raney (1971) also noted the apparent influence of low temperature decreasing abundance in the winter. Their survey data show that the location of this study site is representative of the upper third of the harbor.

This project was funded by General Development Corporation, Miami, Florida, as part of on-going studies of the aquatic biota, water quantity and water quality issues for Charlotte Harbor.

METHODS

Eight, two-minute repetitive 16-foot otter trawls were taken around Marker #1 (26°56.63'N, 82°03.60'W) in upper Charlotte Harbor about once a month to collect fishes and invertebrates from bottom depths of 3.5-4.5m at night after twilight. The net was 5/8-inch mesh with 3/16-inch Ace mesh lining the bag and was towed at 1100 rpms by a 7.3m boat. Timing of the trawl commenced when the line reached 51m. In situ water column profile data were taken at 0.5m intervals for temperature, salinity, dissolved oxygen, pH and redox potential just before the series of trawls. Peace River flow was taken from the USGS station at Arcadia, Florida.

Since freshwater flow is seasonal in Florida, the data are divided into dry season (October-May) and wet season (June-September) (Bradley 1972). Dry season rainfall is usually the result of cold fronts sweeping in from the north, while wet season rainfall is the result of local convective thunderstorms usually influenced by the position and strength of the "Bermuda high pressure system" in the Atlantic Ocean, providing an easterly flow of moisture across the state.

Tidal information was based on the NOAA tide tables for 1971-1980. One ebb tide each day was chosen on the basis of greatest predicted range and examined for long-term variation in the average yearly range. The analysis assumed no effects by climatic conditions (wind speed and direction) or by high freshwater discharge.

Cubic meters per second (m^3/s) is converted to cubic feet per second (cfs) by multiplying by 35.31.

RESULTS AND DISCUSSION

PEACE RIVER FLOWS

About 70 percent of all fresh water measured at USGS gauging stations to Charlotte Harbor passed Arcadia, Florida during this study. Peace River flow is highly variable both within a particular year and between years. During the 49 years of record, annual mean flow ranged from 11.01 m^3/s in 1956 to 72.81 m^3/s in 1960, an increase of over six-fold in a 5-year period. While it may be fortuitous that the high and low records for 49 years occur within the same 5-year period, it dramatically illustrates changes in flow which can occur from year to year.

The river has distinct periods of high and low flow each year. High flow usually occurs from June through October, and low flow from November through May (Table 1). There is commonly an order of magnitude difference between low and high flow in a given year. Even within low and high flow periods, day-to-day flow variation can be large with respect to the monthly or seasonal average flow. This natural variation in flow produces large standard deviations associated with monthly mean flows. For example, the standard deviations associated with each monthly mean flow during the period of record (1931-1980) ranged from 74 percent to more than 100 percent.

During this five-year study period, mean river flow was about 28 percent less than the mean for the period of record (Table 1). Seasonal pattern of the five-year mean flow was not very different except for late winter through early spring (February-April).

Examination, for example, of the wet season freshwater accumulation data provides a means of classifying each year (Figure 1). Two wet seasons, 1975 and 1977, were drier than the others. In 1979 most of the season (June through August) was drier than average. However, flow in September was more than 2.6 times the previous three months, resulting in a seasonal flow ranked as wetter than average (Table 2). Similar analyses were done for the dry season (Figure 2).

The use of specific mean flows in comparison to the long-term means may be misleading, especially if the distribution of monthly flows is skewed, as in the case with Peace River flows. For example, the mean flow for June is 32.3 m^3/s (Figure 3), but 73 percent of the observations are less than the mean. Dry season distributions as exemplified by December plus January are similarly skewed (Figure 4 and Table 1). Wet season median flow for the period of record accumulated by month was about 25 percent less than the long-term mean accumulation. The five years of flow data during this study generally fall on the low side of the median as well as the mean for the long-term frequency distribution. Only July 1978, August 1978 and September 1979 exceed the long-term monthly average for wet seasons (Table 1). October 1979, November 1975, December 1977, January 1978 and 1979, February 1978, March 1978, April 1980, and May 1978, 1979, 1980 exceed the long-term average.

Cyclical patterns in both the wet and dry season flows appear to occur over a 5 to 8 year period (Figures 5 and 6) and average about 6 years. These longer term changes in flow are variable. However, since the high flow peaks in 1959-1960, wet season changes have been much less than those before 1959-60. The high flow peaks in the dry season have been relatively low since the last high peak in 1970.

Cyclical patterns have been found by Shih (1975), for water levels in Lake Okeechobee and the Kissimmee River, and by Meeter et al. (1979), for the flow of the Apalachicola River. These oscillations are variable but tend to repeat at intervals of 5 to 7 years.

The fish data reported here coincide with low points for both the wet and dry seasons and for ascending trends. However, the higher flows are much less then during other intervals.

Table 1. Monthly mean flows (m^3/s) of the Peace River at Arcadia, Florida, for June 1975 through May 1980.

Year	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	$\bar{x}$
1975-76	11.27	22.40	34.01	54.30	41.91	24.98	7.16	5.63	4.44	4.30	3.60	7.42	18.45
1976-77	32.93	51.71	51.91	43.30	18.15	6.71	8.15	9.99	8.27	6.34	2.37	2.40	20.18
1977-78	5.86	21.94	18.01	41.54	13.28	7.87	24.38	21.38	33.53	36.27	5.41	12.91	20.19
1978-79	21.03	74.05	97.36	18.01	7.70	4.59	5.01	29.42	17.87	19.94	3.99	33.67	27.72
1979-80	17.87	18.27	34.49	116.84	85.75	9.45	10.73	11.50	18.66	14.92	30.02	13.17	31.80
$\bar{x}$	17.79	37.67	47.15	54.80	33.35	10.72	11.09	15.58	16.55	16.35	9.08	13.91	
Period of Record Apr 1931-Sep 1980 $\bar{x}$	32.34	54.48	59.84	80.85	46.25	15.38	12.66	16.63	21.24	24.13	18.64	10.78	

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[1] USGS Gauging Station, Provisional Data, Oct 1979 - May 1980.

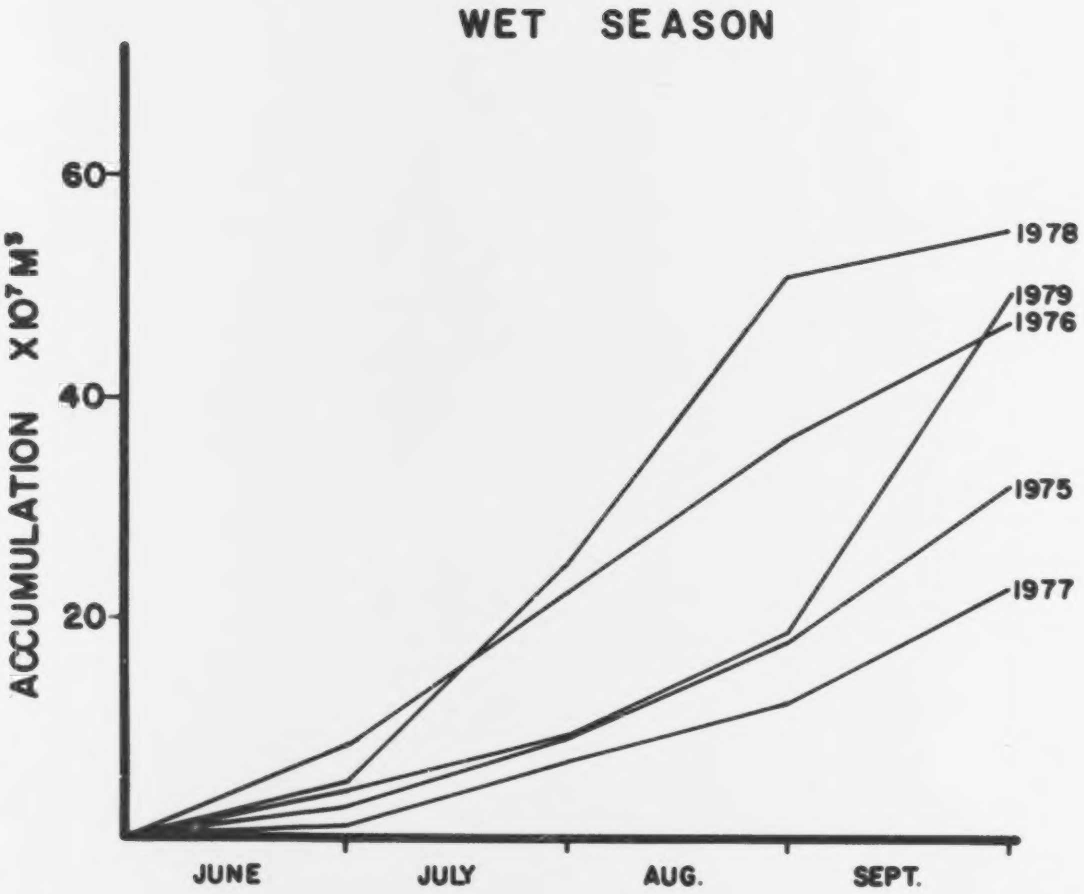

Figure 1. Accumulation patterns of Peace River freshwater flow for 5 wet seasons from 1975 through 1979.

Table 2. Ranking of Mean flows (m^3/s) of the Peace River from highest to lowest for wet and dry season at Arcadia, Florida, from June 1975 to May 1980.

Rank Highest to Lowest Mean Flow	Wet Season[1]		Dry Season[2]	
	Year	Mean Flow	Year	Mean Flow
1	1978	53.2 (18)[3]	1979-80	24.3 (16)
2	1979	46.5 (23)	1977-78	19.3 (26)
3	1976	45.1 (26)	1978-79	15.3 (30)
4	1975	30.4 (37)	1975-76	12.5 (34)
5	1977	21.8 (45)	1976-77	7.8 (39)
Mean Flow (1975-1980)		39.4		15.9
Period of Record (1931-1980)				
Mean Flow		56.9		20.7
Median Flow		45.7		19.3

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[1] June - September

[2] October - May

[3] Rankings for Period of Record.

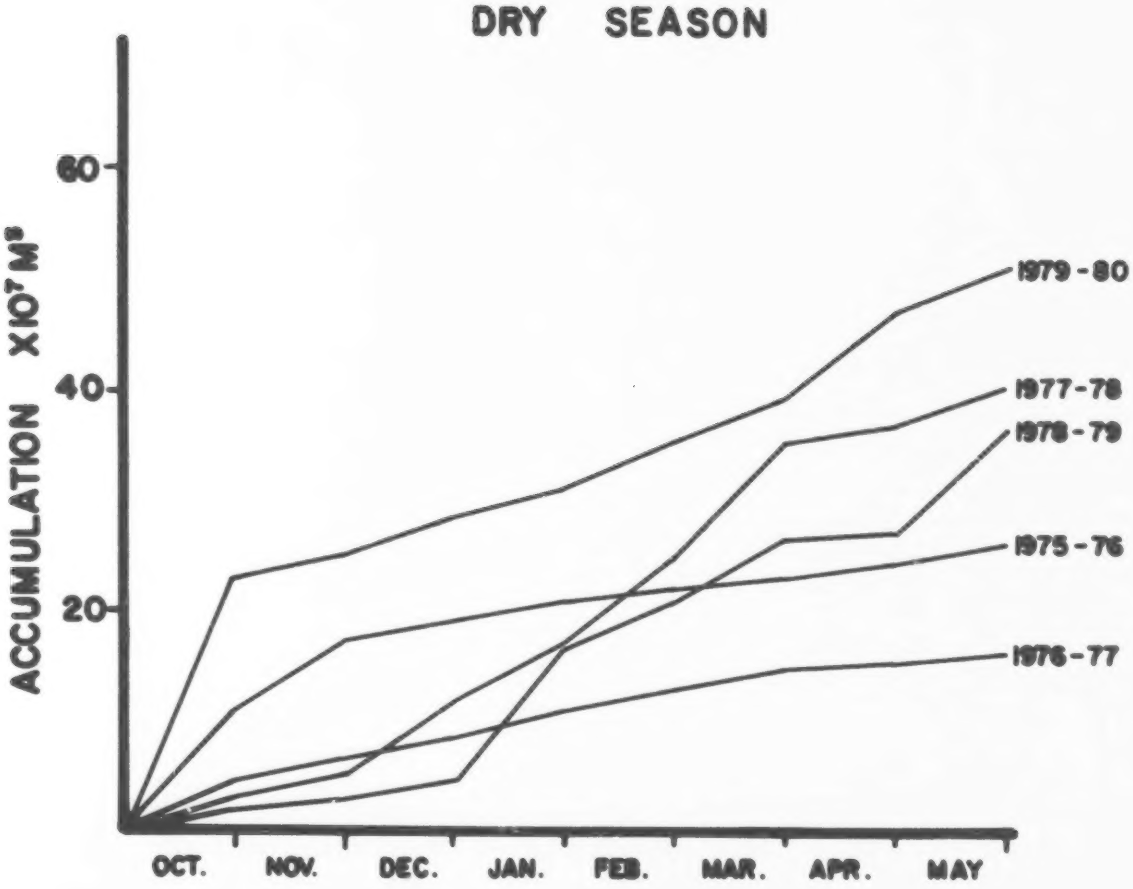

Figure 2. Accumulation patterns of Peace River freshwater flow for 5 dry seasons from 1975 through 1980.

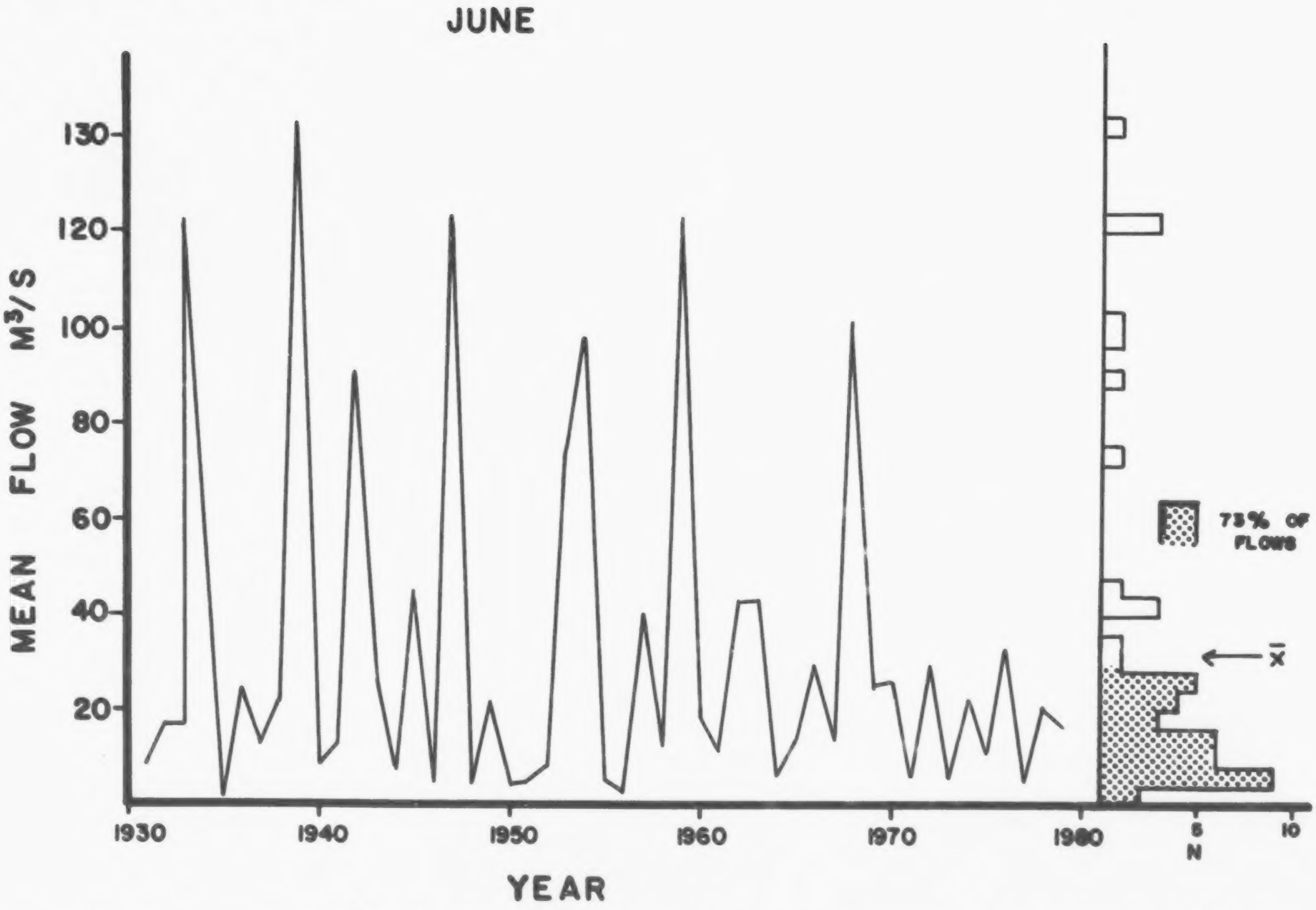

Figure 3. The mean flow (m^3/s) for June from 1931 to 1979 and a frequency distribution by 4 m^3/s intervals.

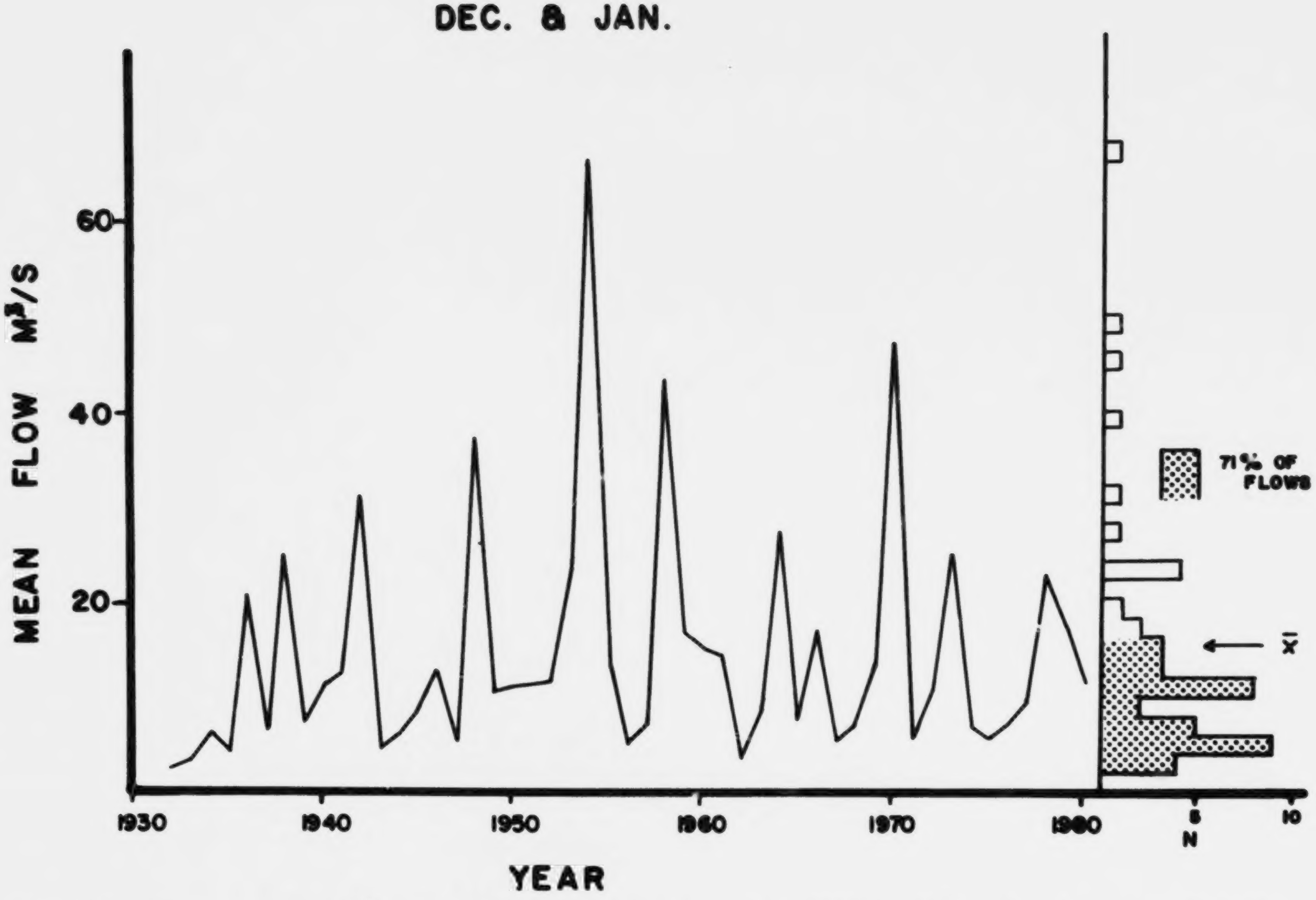

Figure 4. The mean flow (m^3/s for December and January from 1932 to 1980 and a frequency distribution by 2 m^3/s intervals.

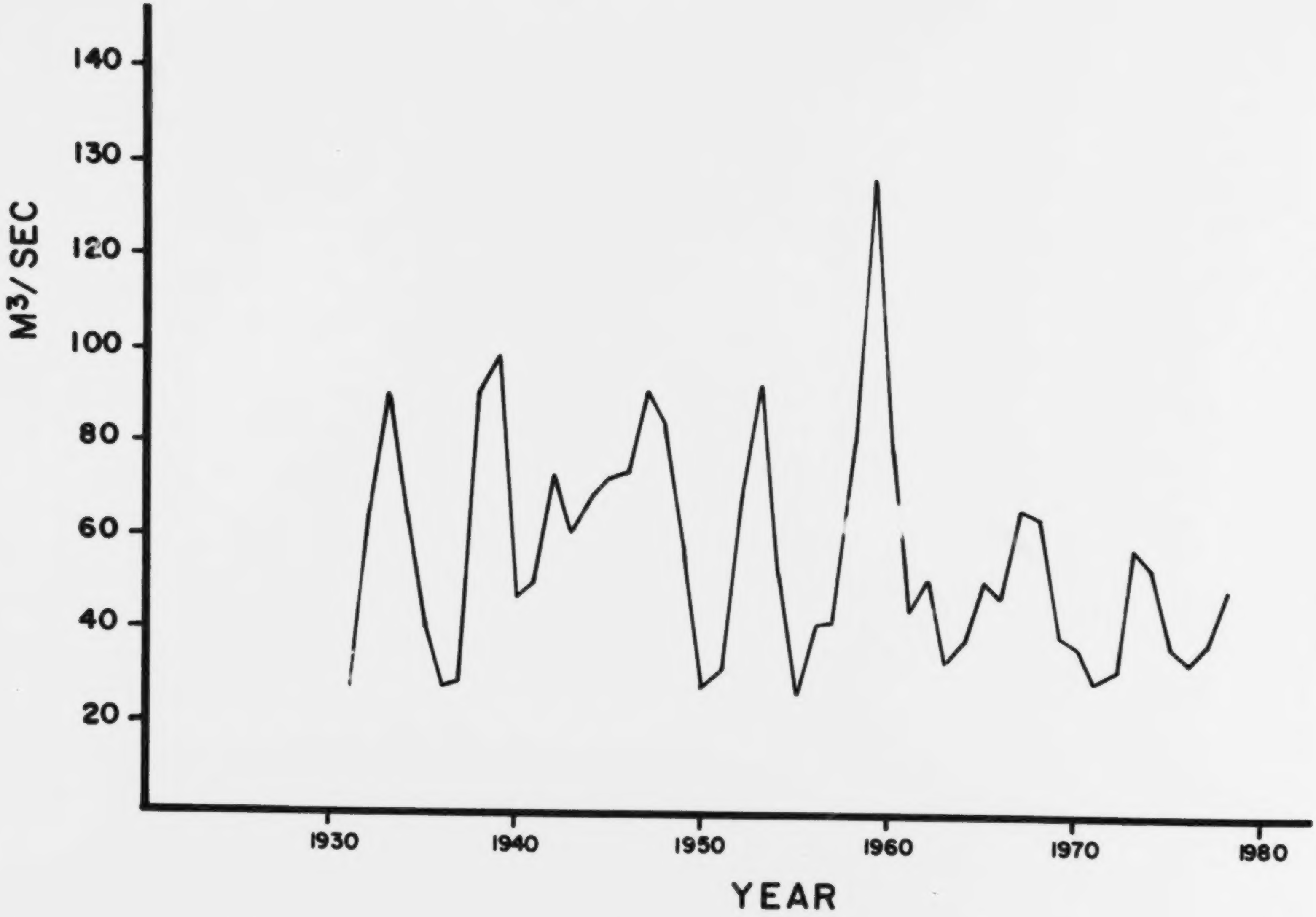

Figure 5. A two-year moving average of mean wet season flows for the Peace River at Arcadia, Florida from 1931 to 1979.

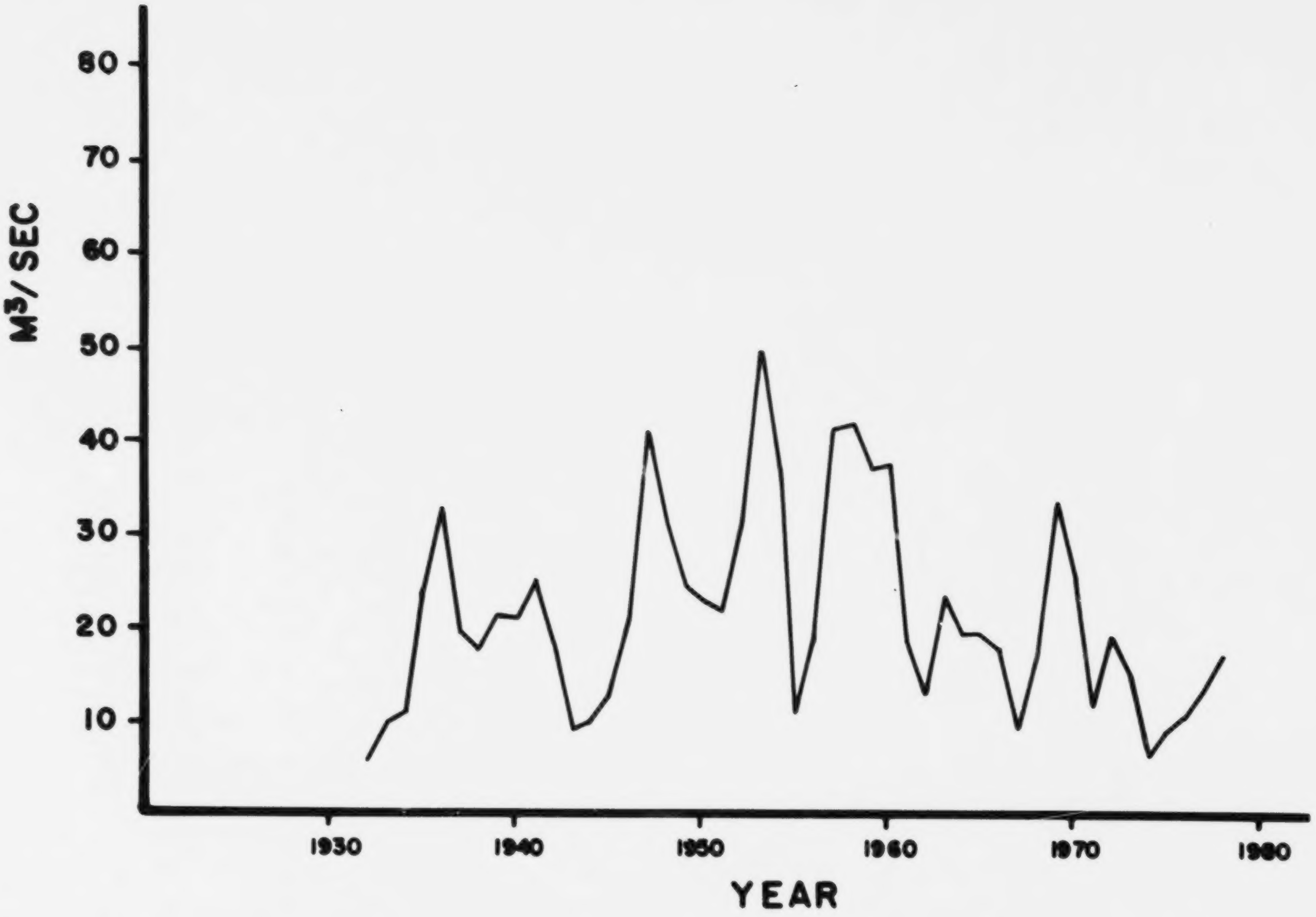

Figure 6. A two-year moving average of mean dry season flows for the Peace River at Arcadia, Florida from 1932 to 1980.

TIDES

Tidal flushing in Charlotte Harbor is subject to long term cycles. One of these cycles lasts for 8.86 years with a 4.43 year span for coincidence of perigee and the farthest northerly and southerly displacement of the moon relative to earth's equator. An analysis of the maximum predicted daily ebb-tide range from 1970 to 1980 suggests that the average annual ebb-tide range can vary by about 10 percent or 6 cm. The minimum range occurred in 1977.

Flushing in Charlotte Harbor, as influenced by river flow and tidal exchange apparently was near a minimum in 1977. A dry season followed by a dry, wet season should result in evaporation exceeding precipitation, coupled with low river flows and a minimum exchange between the estuary and gulf, salinities should rise in the harbor. The longest duration of high salinities occurred in 1977 (Figure 7).

FISH ABUNDANCES

Mean abundances for the five years averaged by month show the annual tendencies for each species (Table 3). The very dry, dry season of 1976-1977 was followed by an extremely dry, wet season (Tables 1 and 2). During the driest wet season (1977) seven taxa (*L. xanthurus*, *A. felis*, *L. rhomboides*, *B. marinus*, *T. maculatus*, *P. scitulus* and *S. plagiusa*) showed abundances not exceeded in any other wet season (Table 4). *Bagre marinus* showed the greatest dry season abundance in the following dry season, unlike the other two species more common in the wet season. Three of these four taxa with usual dry season preference (*L. rhomboides*, *S. plagiusa*, and *P. scitulus*) showed abundance in the following dry season greater than all other dry seasons (Table 5). The presence of *L. rhomboides* during the past five years was basically restricted to the wet season of 1977 and the following dry season.

Influence of one season's abundance on the following dry season appears to be of short duration. Species abundances in the following dry season, 1977-1978, were apparently influenced by the unusual wet season abundances. However, this dry season was also relatively wet and that may have been a confounding influence. The wet season of 1978 showed no apparent influence from the preceding wet or dry seasons of 1977-1978.

The wet season of 1976 was usually low in relative abundance (Table 4). This may be the result of early and high sustained flows that produced adverse conditions or rates of change in Charlotte Harbor salinity and dissolved oxygen (Figure 7). Flows greater than those observed in June 1976 have occurred about 27 percent of the time (Figure 3). This could mean that relative abundances may be as low as or even lower than those observed in 1976 for the upper part of the harbor about 27 percent of the time.

Among the abundant taxa, some species were not collected during some seasons. Two species were not collected at all during the wet season of 1976 and another three species were represented by a total of five specimens (Table 6). In the 1975 wet season three taxa were rare and two were absent. One to three taxa in the remaining wet season were rare or absent. One to four taxa were rare during dry seasons. Taxa frequently showing seasonal rarity were *L. rhomboides*, *B. marinus* and *E. gula*. *Lagodon rhomboides* probably is not a

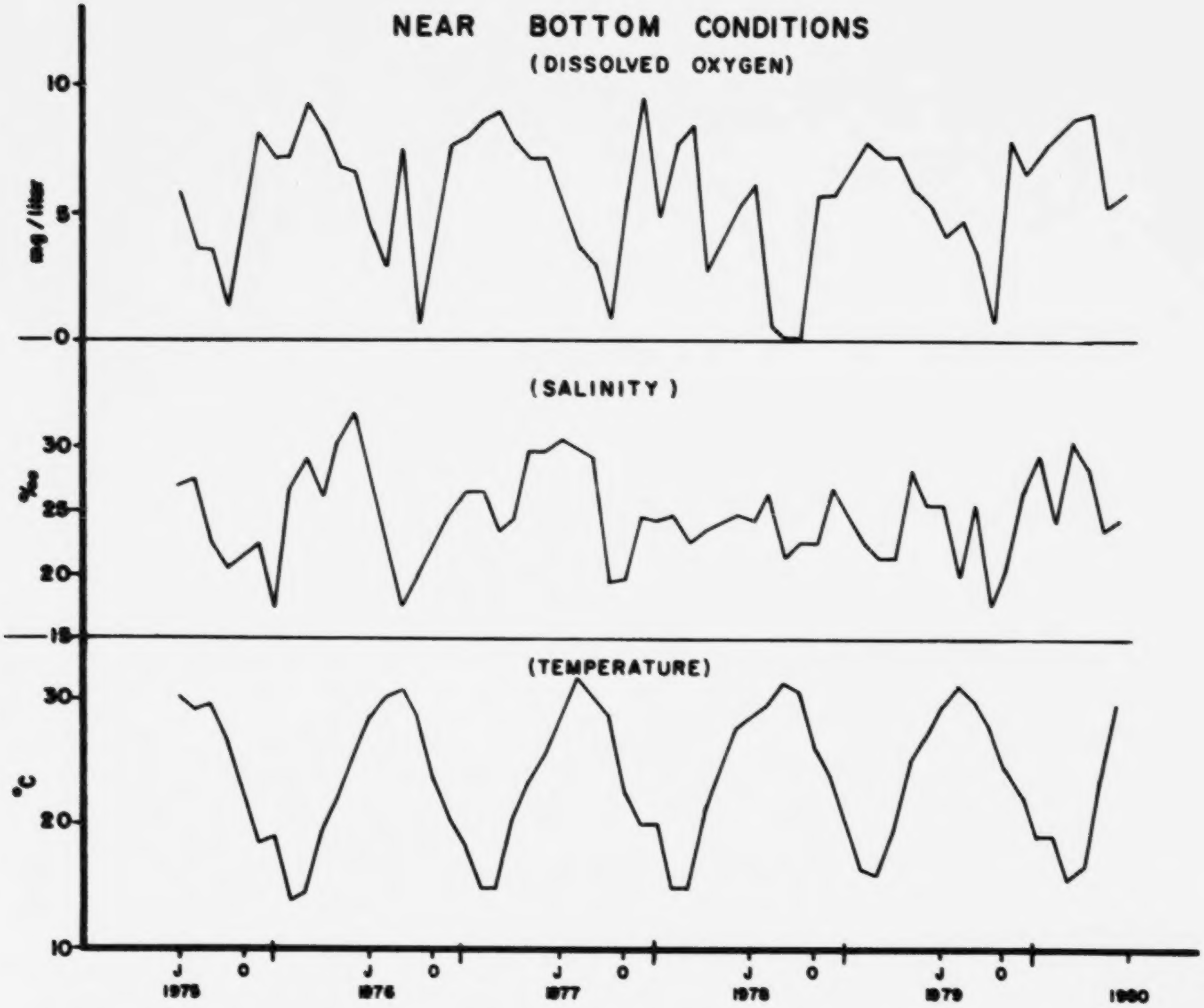

Figure 7. Near bottom dissolved oxygen, salinity and temperature near Marker #1 (26°56.63'N, 82°03.60'W) on the sample site.

Table 3. The average number of specimens for the 12 most abundant benthic fishes in upper Charlotte Harbor by month for 5 years and predominant season of abundance.

PREDOMINANT SEASON	SPECIES	MONTH												
		JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	$\bar{x}$
W E T	*Cynoscion arenarius*	369	157	333	60	198	7	3	3	4	2	2	22	97
	Leiostomus xanthurus	72	149	65	<1	3	4	10	7	1	9	157	143	52
	Arius felis	7	9	277	4	164	57	28	2	3	18	20	70	55
	Bagre marinus	4	6	52	12	11	4	13	4	0	<1	0	1	5
D R Y	*Anchoa mitchelli*	406	140	29	82	69	103	134	132	401	202	197	166	172
	Menticirrhus americanus	29	14	19	5	102	27	12	12	14	24	22	21	25
	Lagodon rhomboides	2	5	7	<1	3	9	49	28	3	2	<1	6	10
	Trinectes maculatus	20	9	12	1	60	20	11	2	8	4	19	18	15
	Symphurus plagiusa	7	14	5	1	1	3	10	9	12	13	13	11	8
	Eucinostomus gula	1	9	7	<1	4	15	39	7	7	1	1	1	8
	Prionotus scitulus	11	11	10	<1	1	8	18	12	15	6	4	2	8
	Bairdiella chrysura	2	6	1	4	21	3	8	<1	<1	2	3	1	4

Table 4. The average number of specimens for the 12 most abundant benthic fishes in upper Charlotte Harbor by ranked wet season for 5 years.

		RANK				
		1	2	3	4	5
	SPECIES	1978	1979	1976	1975	1977
1	*Anchoa mitchelli*	420	91	44	82	92
2	*Cynoscion arenarius*	71	178	41	567	273
3	*Arius felis*	0	216	4	11	255
4	*Leiostomus xanthurus*	34	82	3	0	271
5	*Menticirrhus americanus*	19	23	4	27	8
6	*Trinectes maculatus*	3	11	5	9	27
7	*Lagodon rhomboides*	2	<1	<1	0	26
8	*Bagre marinus*	5	37	1	6	67
9	*Symphurus plagiusa*	3	2	3	1	26
10	*Prionotus scitulus*	11	<1	0	2	30
11	*Eucinostomus gula*	1	12	0	8	1
12	*Bairdiella chrysura*	3	6	<1	<1	8

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[1] Wet Season: June - September.

Table 5. The average number of specimens for the 12 most abundant benthic fishes in upper Charlotte Harbor by ranked dry season for 5 years.

			RANK		
	1	2	3	4	5
SPECIES	1979-80	1977-78	1978-79	1975-76	1976-77
Anchoa mitchelli	83	206	251	184	124
Cynoscion arenarius	27	9	74	3	2
Arius felis	158	25	21	< 1	1
Leiostomus xanthurus	2	22	55	2	132
Menticirrhus americanus	16	11	75	22	6
Trinectes maculatus	14	12	37	5	10
Lagodon rhomboides	<1	56	< 1	< 1	4
Bagre marinus	5	12	1	< 1	< 1
Symphurus plagiusa	5	19	6	10	6
Prionotus scitulus	6	17	3	6	8
Eucinostomus gula	17	15	< 1	13	1
Bairdiella chrysura	7	7	1	4	< 1

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[1] Dry Season: October - May.

Table 6. A summary by season and year of the total catch and number of sample dates for June 1975 through May 1980 of the 12 most abundant benthic fishes in upper Charlotte Harbor.

		Jun 75 - May 76			Jun 76 - May 77			Jun 77 - May 78			Jun 78 - May 79			Jun 79 - May 80			
	SPECIES	WET	DRY	ANNUAL	WET	DRY	ANNUAL	WET	DRY	ANNUAL	WET	DRY	ANNUAL	WET	DRY	ANNUAL	GRAND TOTAL
1	*Anchoa mitchelli*	327	1101	1428	177	870	1047	277	1441	1718	1681	1758	3439	272	581	853	8485
2	*Cynoscion arenarius*	2268	20	2288	162	13	175	819	63	882	284	520	804	536	189	725	4874
3	*Arius felis*	44	4	48	13	7	20	764	175	939	0	146	146	648	1105	1753	2906
4	*Leiostomus xanthurus*	0	10	10	11	923	934	814	156	970	137	383	520	247	17	264	2698
5	*Menticirrhus americanus*	109	133	242	16	41	57	25	76	101	76	526	602	69	115	184	1186
6	*Trinectes maculatus*	35	32	67	19	68	87	82	80	162	11	261	272	32	99	131	719
7	*Lagodon rhomboides*	0	4	4	1	25	26	78	395	473	7	4	11	1	4	5	519
8	*Bagre marinus*	22	2	24	3	1	4	202	86	288	14	7	21	112	38	150	487
9	*Symphurus plagiusa*	3	57	60	12	45	57	77	130	207	11	39	50	7	37	44	418
10	*Prionodes scitulus*	7	33	40	0	58	58	90	118	208	42	22	64	1	44	45	415
11	*Eucinostomus gula*	32	79	111	0	7	7	3	107	110	3	1	4	35	118	153	385
12	*Bairdiella chrysura*	2	21	23	1	1	2	23	50	73	13	10	23	18	49	67	188
	TOTAL	2849	1496	4345	415	2059	2474	3254	2877	6131	2279	3677	5956	1978	2396	4374	23280
	NUMBER OF SAMPLE DATES	4	6		4	7		3	7		4	7		3	7		

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[1] Wet period, June - September
Dry period, October - May
Annual period, June - May

usual community member of this nonvegetated bottom. All other species have occurred often enough to support their inclusion as typical members. Reasons for species having large changes in abundances from one year to the next are not understood, for example, *E. gula* appears to alternate years of high then low abundance.

Extreme cold in January and February 1977 (Gilmore et al. 1978) may be responsible, in part, for the two lowest abundances recorded in the dry season. *Arius felis*, *Bagre marinus*, *Eucinostomus gula*, *Lagodon rhomboides* *Bairdiella chrysura*, *Leiostomus xanthurus* and *Menticirrhus* spp. have been reported as being killed by cold snaps in central and southern Florida (see Gilmore et al. 1978) at one time or another. Among these species, only three specimens of *Lagodon rhomboides* were caught during this period. No dead or dying specimens were observed in the sample area. Ambient water temperature during January and Febraury 1977 was similar in 1978 (Figure 7) but slightly warmer than in 1976. Among cold-sensitive species, only *Menticirrhus americanus* and *Eucinostomus gula* were caught in 1976 and again in 1978 along with *Leiostomus xanthurus*, *Arius felis*, *Lagodon rhomboides* and *Biardiella chrysura*. Gilmore et al. (1978) suggest that the rate of cooling and duration of cold influences mortality. Even though temperatures may appear similar, based on sampling once or twice a month, daily observations are needed to account for abundance changes that may be related to winter minima.

Relative abundances generally are lower near the end of the wet season (Table 7). Among the environmental changes resulting from high flows, both salinity and dissolved oxygen decrease (Figure 8). These two factors may be responsible, in part, for low abundances. Each September sample produced low abundances along with lowest dissolved oxygen, high temperature, and low salinities (Figure 7), as well as low pH and high color (unpublished obs.).

The upper third of the harbor probably experiences severe flow-related changes usually during September each year (Table 1 and Figure 7). Abundances may be reduced to near zero in higher flow years since the long-term average in September is 33 percent greater than the average for 5 years of study. Extreme abundance reductions may, in part, be related to previous high flow months, for example, June to September 1976 and June to August 1979 (Table 7). Thus, if the flows for a given wet season were similar to the period of record average for each month, we would expect to observe not only a low average abundance for the wet season but also extremely reduced abundances during September.

Although simple rankings with abundance data suggest no obvious trends (Table 8), grouping on the basis of flow patterns (Figures 1 and 2) does suggest a trend. The wet seasons of 1975, 1977 and 1979 had higher abundances than 1976 or 1978. Likewise, the dry seasons of 1977-1978, 1978-1979 and 1979-1980 had higher abundances than 1975-1976 or 1976-1977.

Figures 8 and 9 show these flow-abundance relationships for particular flows and seasonal abundance. When the mean river flow for two short periods of time is plotted with the mean seasonal abundance of the 12 taxa, a nearly straight line relationship is formed ($R^2 = .95$ for both figures). Data in Tables 4 and 5 show that no single species is responsible for the trend of the points. A sum of the four most abundant species will produce a similar line in the wet season and the seven most abundant species will produce a similar line in the dry season from

Table 7. The total number of specimens by month for the 12 most abundant benthic fishes in upper Charlotte Harbor form June 1975 through May 1980.

	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	TOTAL	$\bar{x}$
1975-76	1412	151	1087	199	-	110	110	76	-	532	405	263	4345	435
1976-77	149	192	32	42	-	221	100	28	35	293	523	859	2474	225
1977-78	-	1215	1781	258	175	275	717	329	1011	208	-	162	6131	613
1978-79	1627	575	16	61	1129	367	-	550	367	164	523	577	5956	541
1979-80	521	-	1169	288	608	326	401	107	-	222	305	427	4374	437
TOTAL	3709	2133	4085	848	1912	1299	1328	1090	1413	1419	1756	2288	23280	-
$\bar{x}$	927	533	817	170	637	260	332	218	471	284	439	458		448

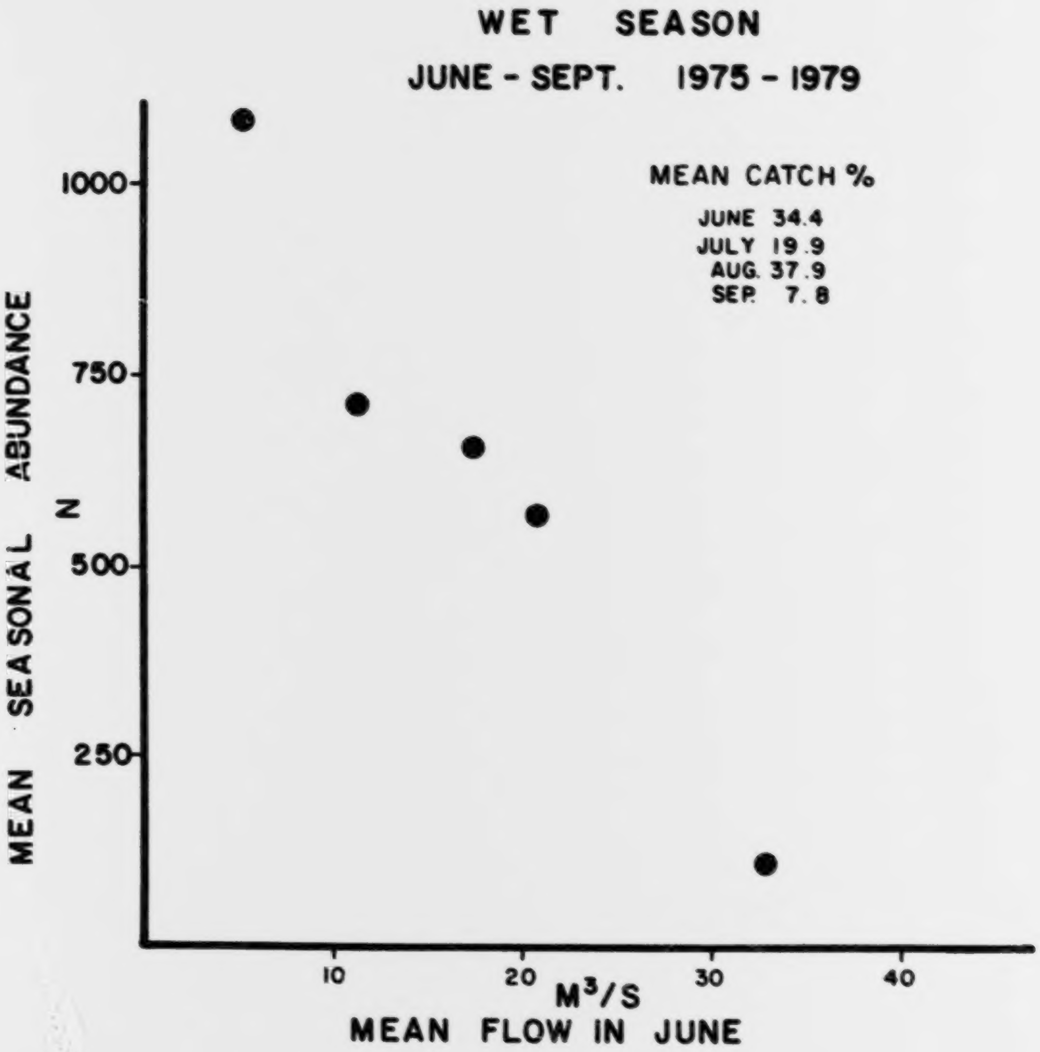

Figure 8. Mean Peace River flow in June for each year (1975-1979) and the mean abundance of benthic fishes (12 taxa) in upper Charlotte Harbor for the wet season. A least squares linear fit of the points yields the following equation : $x = -33.32y + 1218.5$, and a correlation coefficient of -0.974.

Table 8. Average seasonal abundance of the 12 most abundant fishes in upper Charlotte Harbor and flow ranking of the Peace River for 5 years.

	WET SEASON			DRY SEASON			ANNUAL	
FLOW RANK Highest to Lowest	Year	Average Abundance	Taxa	Year	Average Abundance	Taxa	Year	Average Abundance
1	1978	570	11	1979-80	342	12	1979-80	437
2	1979	659	12	1977-78	411	12	1978-79	541
3	1976	104	10	1978-79	525	12	1977-78	613
4	1975	712	10	1975-76	249	12	1976-77	225
5	1977	1085	12	1976-77	294	12	1975-76	435

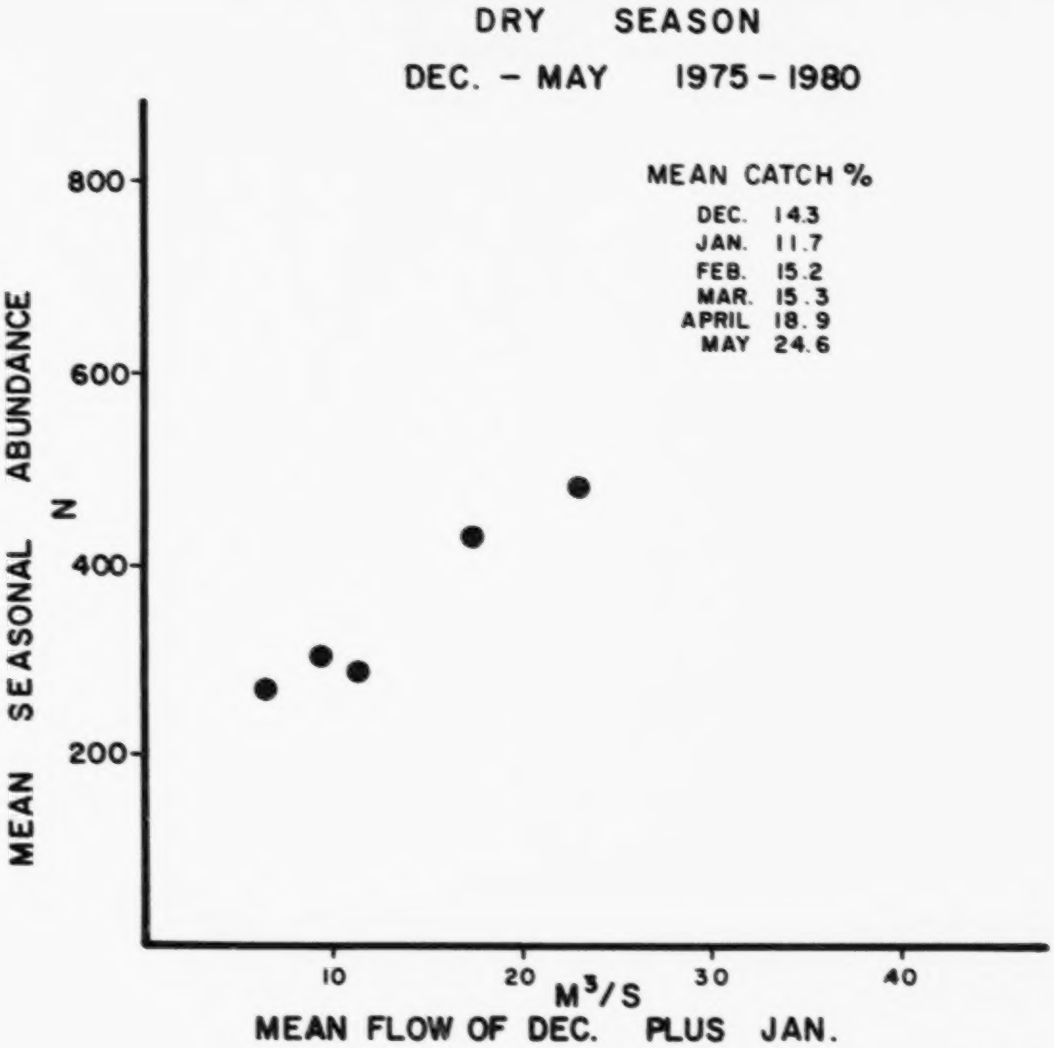

Figure 9. Mean Peace River flow in December and January for each year (1975-1980) and mean abundance of benhtic fishes (12 taxa) in upper Charlotte Harbor for the dry season months of December through May. A least squares linear fit of the points yields the following equation: x = 13.70y + 177.7 , and a correlation coefficient of 0.976.

December to May. Flows in June and December plus January are poorly correlated with subsequent seasonal flows for the period of record (R^2 values less than 0.3).

Perhaps long-term trends might occur for abundances of fishes in the upper third of Charlotte Harbor as a result of specific variations in river flow. If the general trends observed for this data set are descriptive for relationships between flow and abundance, then one might expect average abundance to follow the flows. Thus, for wet season average abundance would be inversely related to flow in June (Figure 8) and dry season average abundance directly related to flow in December-January (Figure 9).

Comparisons of relative abundances showed that among the top six species in Apalachicola Bay (Sheridan and Livingston 1979), three were among the top six in Charlotte Harbor (*Anchoa mitchilli Leiostomus xanthurus* and *Cynoscion arenarius*). In both estuaries *mitchilli* was most abundant. The abundance pattern of *A. mitchilli* was apparently different in Charlotte Harbor with peaks in February and June rather than October-November in Apalachicola Bay. *Cynoscion arenarius* was abundant in Charlotte Harbor during the summer with peaks in June and August, rather than May and August. *Leiostomus xanthurus* was abundant in Charlotte Harbor from April through August with peaks in April-May and July, rather than in March.

CONCLUSIONS AND RECOMMENDATIONS

Upper Charlotte Harbor

1. Year-to-year variation in river flow, particularly during the beginning of the wet season and near the end of declining temperature in the dry season, were correlated with fish abundance.

2. Extremely dry, wet seasons are accompanied by obvious increase in the abundance of very common species as well as the appearance of species not abundant during wetter wet seasons.

3. Changes in abundance during extremely dry, wet seasons may influence abundance in the following dry season.

4. Extremely cold temperatures can temporarily influence abundance and presence of taxa for short periods.

5. Long-term periodicity in river flow may average about six years for both wet and dry seasons. The amplitude in flows may be quite variable.

6. Coincidence of other regular long-term cycles such as tidal flushing may enhance environmental changes produced by fluctuating river flow.

7. It seems reasonable to expect some supra-annual oscillation in fish abundance related to changes in flow. The limits of variation are not clear, for the data only approach the known low-flow spectrum but are not even close to the known high-flow spectrum.

Charlotte Harbor and Apalachicola Bay

1. At least some of the more common taxa in both estuaries show abundance patterns that are dissimilar in time. These differences could be an expression of the variation in the physical characteristics of the estuaries without implying

significant genetic populational differences. Although, depending on life history patterns, this may be one indication of major estuaries having distinct subpopulations such as described by Weinstein and Yerger (1976) for Cynoscion nebulosus.

2. Long-term periodicity in the flow of the Apalachicola River and the Peace River, while approximately similar in duration, may be the result of regional (local) climatic effects. Thus, it may be important to view general estuarine changes in periods much longer than the annual cycle in order to identify natural population oscillations from those resulting from man-made changes in flow.

Southwest Florida

Many of the observations for Charlotte Harbor, particularly in terms of the fauna, seasonal patterns of flow, long-term cycles may have analogues from about Estero Bay to Tampa Bay because of similar climatic and tidal conditions.

LITERATURE CITED

Bradley, J.T.The climate of Florida. Climates of the United States; Water Information Center, Inc.; 1972; 1:45-70.

Finucane, J.H.; Faunal production project. U.S. Fish Wildlife Service; 1966:18-20. Circular 242.

Gilmore, R.G.; Bullock, L.H.; Berry, F.H. Hypothermal mortality in marine fishes of south-central Florida, January 1977. Northeast Gulf Science 2 (2):77-97; 1978.

Livingston, R.J.; Kobylinski, G.J.; Lewis, F.G.; Sheridan, P.F. Long-term fluctuations of epibenthic fish and invertebrate populations in Apalachicola Bay, Florida. Fishery Bulletin 74: 311-321; 1976.

Livingston, R.J.; Thompson, N.P.; Meeter, D.A. Long-term variation of organochlorine residues and assemblages of epibenthic organisms in a shallow north Florida (USA) estuary. Marine Biology 46:355-372; 1978.

Meeter, D.A.; Livingston, R.J.; Woodsum, G.C. Long-term climatological cycles and population changes in a river-dominated estuarine system. In: Ecological Processes in Coastal and Marine Systems. Marine Science 10; New York: Plenum Press; 1979:315-338.

Sheridan, P. F.; Livingston, R. J. Cyclic trophic relationships of fishes in an unpolluted, river-dominated estuary in North Florida. Ecological Processes in Coastal and Marine Systems. Marine Science 10; Plenum Press; 1979:143-161.

Shih, S.F.; Time series analysis and its application to water resources. Proceedings Second World Congress, International Water Resources Association; 1975; 5:223-236.

Taylor, J.L.; The Charlotte Harbor estuarine system. Florida Scientist; 37 (4): 205-216. 1974.

Wang, J.C.S.; Raney, E.C. Distribution of fluctuations in the fish fauna of the Charlotte Harbor estuary, Florida. Mote Marine Laboratory; Charlotte Harbor Estuarine Studies; 1971; 1-56.

Weinstein, M.P.; Yerger, R.W.; Protein taxonomy of the Gulf of Mexico and Atlantic Ocean seatrouts, genus Cynoscion. Fisheries Bulletin 74(3): 599-607.

RIVER-DERIVED INPUT OF DETRITUS INTO THE APALACHICOLA ESTUARY

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ABSTRACT

The exact significance of river-derived particulate organic matter to estuarine biota remains in doubt. This is due, in part, to al lack of information regarding temporal (seasonal, annual) features of detrital loading. Quantitative as well as qualitative aspects of such detritus movement are probably an important feature of estuarine productivity. Long-term (5-year) studies of detritus movement into the Apalachicola estuary indicate that the timing of river flow peaks, together with changes in the wetlands vegetation along the flood plain and macrophyte cycles within the estuary, are important determinants of short- and long-term trends of the input of particulate organic matter. Research by the Florida State University Aquatic Study Group is currently addressing the specific response of estuarine biota to multiple climatological factors in an attempt to evaluate the biological significance of river flow into the Apalachicola estuary.

INTRODUCTION

River-derived freshwater input has various effects on receiving coastal systems. Some studies have described the production and movement of particulate organic matter in streams and rivers (Kaushik and Hynes, 1971; Hynes et al., 1974; de la Cruz and Post, 1977). De la Cruz (1979) has reviewed various aspects of the production and transport of detritus in estuaries. Post and de la Cruz (1977) estimated the transport of allochthonous particulate organic matter into a gulf coast bay and found that variation of net input depended on qualitative features of the leaf litter and the hydrological features of the system. Various factors such as local meteorological conditions, flow variation, litter fall and decomposition rates, river size and configuration, topography of the drainage system and physiography of the receiving estuary are all involved with the net input of organic matter to river-dominated estuaries. While various studies indicate that there is considerable seasonal and annual variation in sediment discharge into bay systems, there is relatively little information concerning the qualitative composition of particulate organic matter as it moves into coastal areas and the temporal variability of such movement. Such aspects of detrital flux could be of importance to the biological organization of the receiving estuary although there are few analyses that take into consideration the timed interactions of upland watersheds and downstream dependent systems (Livingston and Loucks 1979). Indeed, the biological significance of detritus fluxing in such systems remains in doubt (Haines 1979; Odum et al. 1979).

The present study is part of a comprehensive long-term program to determine the functional relationships of hydrology (Meeter et al. 1979), energy relationships (White et al. 1979), food web characteristics (Sheridan and Livingston, 1979), and the timed interactions of river inflow and biological productivity (Livingston and Loucks 1979) in the Apalachicola estuary. This paper will address specific questions related to the timing (seasonal, annual) of net inflow of particulate organic matter to the Apalachicola Bay system.

MATERIALS AND METHODS

A monitoring program was established to estimate short- and long-term trends of river-derived detrital input into the Apalachicola estuary. Sampling stations were established along the lower reaches of the river (Figure 1: stations 7, 8). Surface and bottom samples were taken at station 7; mid-depth samples at station 8. Once each month, from August 1975 to the present, water was pumped through a series of sieves (mesh size: 2.00, 1.00, 0.500, 0.250, 0.125, 0.090, 0.045 mm). All samples were taken on a falling tide. The amount of processed water depended on local conditions and varied from 50 to 1000 liters. Detritus samples were preserved in 2 percent $HgCl_2$. Details of the laboratory procedures are given by Livingston et al. (1976). Dry weight (dried at 100°C for 24 hours) and ash-free dry weight (dried at 500°C for one hour) determinations were made for each sample (± 0.001 g). All such samples are referred to as microdetritus, and only total values (i.e., all sieves) were used for this study.

A qualitative estimate of the identifiable particulate matter in the estuary (macrodetritus) was made by analyzing monthly trawl tow samples (32 replicate 2-minute tows with a 5-m otter trawl at 11 permanent stations; Figure 1) from January, 1975, to the present. Samples were preserved in the field with 10 percent buffered formalin. In the laboratory, the detrital samples were identified according to origin (macrophyte or tree species, where possible), dried (100°C for 24 hours), and weighed (± 0.01 g). Data were expressed as dry weight totals per sample.

River flow data (Blountstown, Florida) were provided by the U. S. Army Corps of Engineers (Mobile, Alabama). Air temperature and local rainfall data were provided by the Environmental Data Service (National Oceanic and Atmospheric Administration, Apalachicola, Florida). Rainfall data in the Tate's Hell Swamp were provided by the East Bay forestry tower (Apalachicola, Florida).

RESULTS AND DISCUSSION

Various studies (Livingston et al. 1977; Livingston and Duncan, 1979; Meeter et al., 1979) have indicated the relative importance of meterological conditions such as temperature, local rainfall, and river flow on the spatial and temporal aspects of habitat in the Apalachicola estuary. Such functions, over the study period (1975-1980), are shown in Figure 2a. While the average summer high temperature

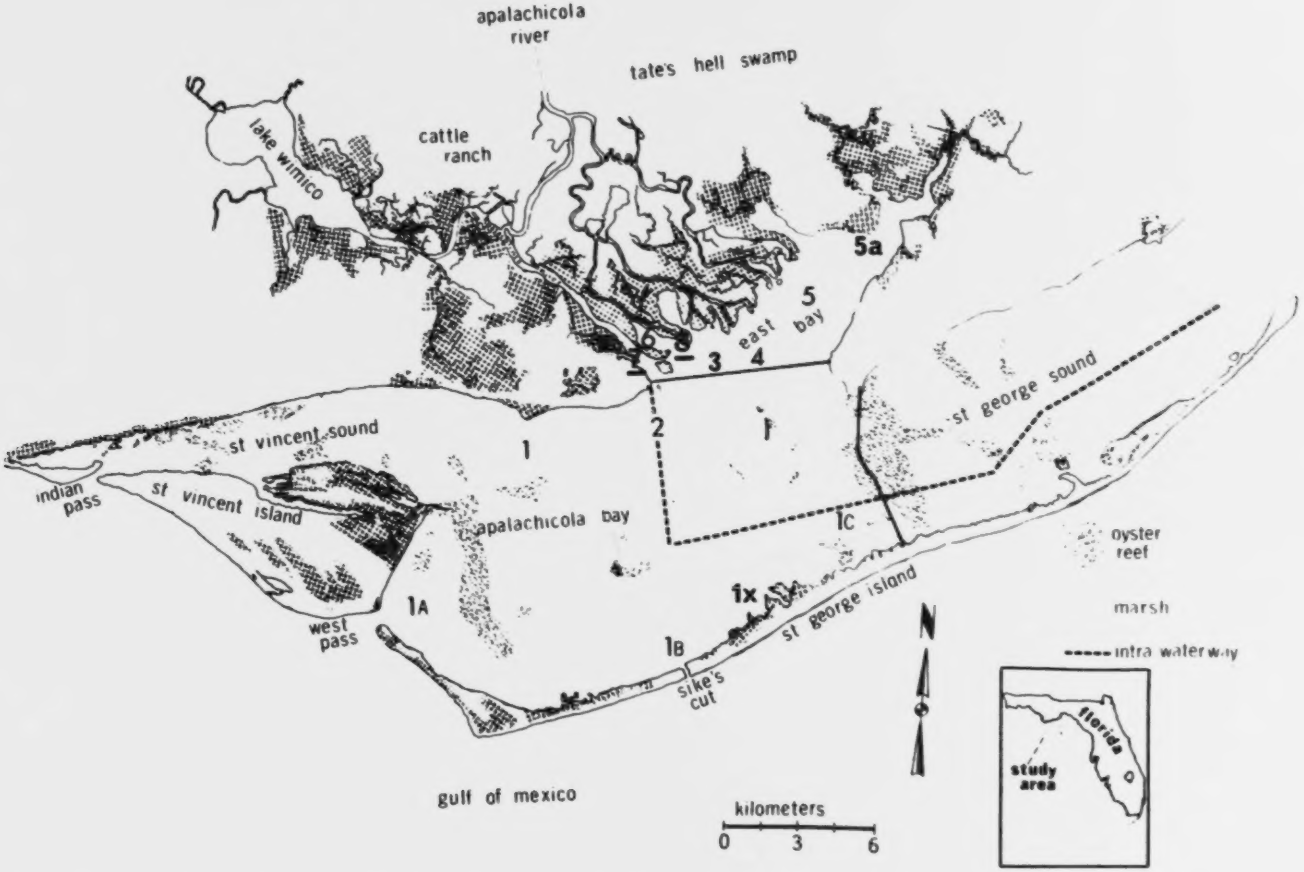
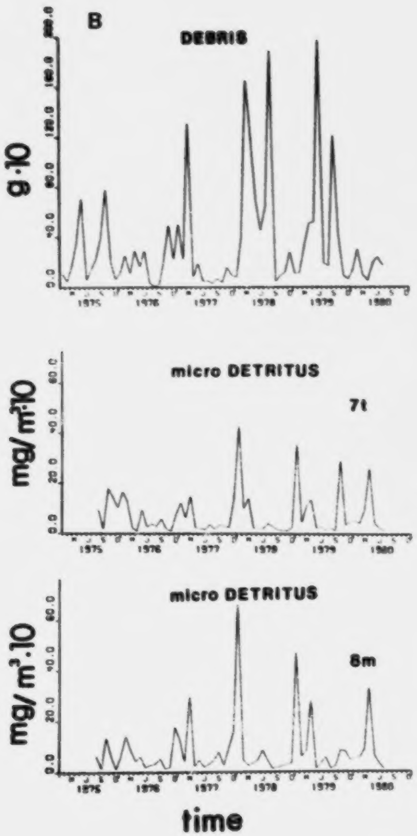

apalachicola river
tate's hell swamp
lake wimico
cattle ranch
5a
5
east bay
4
3
2
1
st vincent sound
indian pass
st vincent island
apalachicola bay
1C
st george sound
oyster reef
marsh
intra waterway
1X
1A
west pass
1B
sike's cut
st george island
N
gulf of mexico
kilometers
0
3
6
florida
study area

Figure 1. Chart of the Apalachicola estuary showing permanent stations for otter trawling, water quality analysis, and macrodetritus distribution (1, 2, 3, 4, 5, 5A, 1A, 1B, 1C, 1E, 1X). Also shown are microdetritus stations sampled at the surface and bottom (7) and at mid-depth (8).



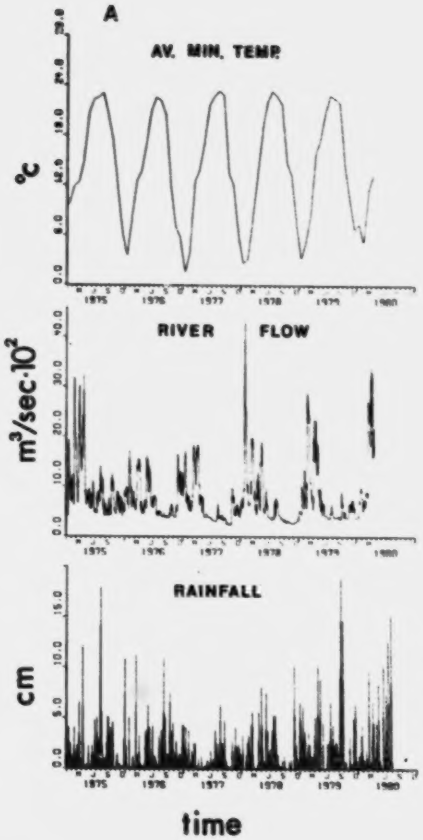


Figure 2A. Monthly average minimum temperature (Apalachicola; °C), daily average Apalachicola River flow (m^3/second), and daily total East Bay rainfall from January, 1975, through the spring and early summer of 1980.

Figure 2B. Monthly totals of macrodetritus (debris; g dry weight) and microdetritus (mg ash-free dry weight) in the Apalachicola estuary from January, 1975, to August, 1980. Debris is taken from trawl samples at permanent stations within the estuary while microdetritus is taken from surface samples at station 7 and mid-depth samples from station 8.

did not vary to any extent, there was a progressive decline in winter low temperatures over the first three years with a minimum occurring during January, 1977. This was followed by progressively warmer winters (1978-1980). Apalachicola River flow was seasonal with the highest daily peaks occurring during winter and spring months. After moderately high flows in 1975, there was a two-year period of relatively low winter-spring flows (1976-1977). This was followed by a series of high peaks in the early winter months of 1978 and spring of 1979 and 1980. Local rainfall peaked during summer-fall periods with relatively high rainfall in 1975. This was followed by a period of low rainfall (1976 through 1978). Increased precipitation was observed in 1979 and 1980. These data indicate various phase differences in the climatological features of the study area as part of longer-term cycles (Livingston and Duncan 1979; Meeter et al. 1979).

Analysis of the temporal variation of macrodetritus and microdetritus is given in Figure 2b. A qualitative determination of the macrodetrital component indicates spatial differences in detrital distribution (Livingston et al. 1977). Areas dominated by the Apalachicola River have winter peaks of wood debris and leaf litter derived from wetlands vegetation along the river flood plain. Dominant plant forms represented in the detritus include oaks (*Quercus* spp), cottonwood (*Populus deltoides*),sweetbay (*Liquidambar styraciflua*), tupelo (*Nyssa aquatica*),river birch (*Betula nigra*), and maples (*Acer rubrum*). Detritus in the outer bay stations, farthest from river input, was dominated by various macrophytes including seagrasses and algae. Benthic macrophyte-derived detritus usually peaked in late summer or fall, reflecting growth and decay patterns of *Ruppia maritima*, *Ulva lactuca*, *Halodule wrightii*, *Vallisneria americana*, and *Gracilaria* spp.

A bimodal seasonal cycle of estuarine detrital peaks was superimposed over a long-term trend that tended to reflect supra-annual variation of river flow. The first seasonal peak of debris was absent during 1980 at which time river flow tended to peak later in the spring. There were indications that although the amount of debris in the bay tends to follow river flow conditions, the specific time of the year of river flooding is also an important factor in the amount of available detritus. The long-term trends of microdetritus were somewhat consistent with this pattern (Figure 2b), and the highest levels of such particulate matter tended to coincide with maximal river peaking early in the year. (January-February). Such peaks in microdetritus usually were closely associated with river flow peaks in time whereas the macrodetritus showed differential lags as explained by Livingston et al. (1977). Thus, there were short- and long-term associations of available detritus and river flow conditions (i.e., seasonal peaks) that reflected qualitative differences in the form of the organic matter as well as the seasonal distribution of river peak phenomena. Overall, peak detrital flows reflected seasonal river flow patterns with major peaks occurring during winter-spring months. Such patterns of total detrital loading (flux) followed detrital concentrations (mg ash-free dry weight/m^3 in the Apalachicola River.

A linear regression of microdetritus and river flow by season (Table 1, Figure 3) indicated that there are seasonal differences in the relationship of detrital concentration and river flow. During summer periods, there is no

Table 1. Linear Regression (log/log) of total microdetritus (ash-free dry weight) and riverflow (m^3/sec) by month/year by Season (8/75-4/80).

Station 7 (Surface)	R	R^2	α (significance)
June-August	0.08	0.23	0.39863
September-November	0.48	0.23	0.03469
December-February	0.70	0.49	0.00188
March-May	0.77	0.60	0.00057
Station 7 (Bottom)			
June-August	0.08	0.01	0.40243
September-November	0.21	0.04	0.22867
December-February	0.77	0.60	0.00037
March-May	0.55	0.30	0.02253
Station 7 (Mid-depth)			
June-August	0.35	0.12	0.11809
September-November	0.19	0.04	0.25542
December-February	0.64	0.40	0.00570
March-May	0.68	0.46	0.00397

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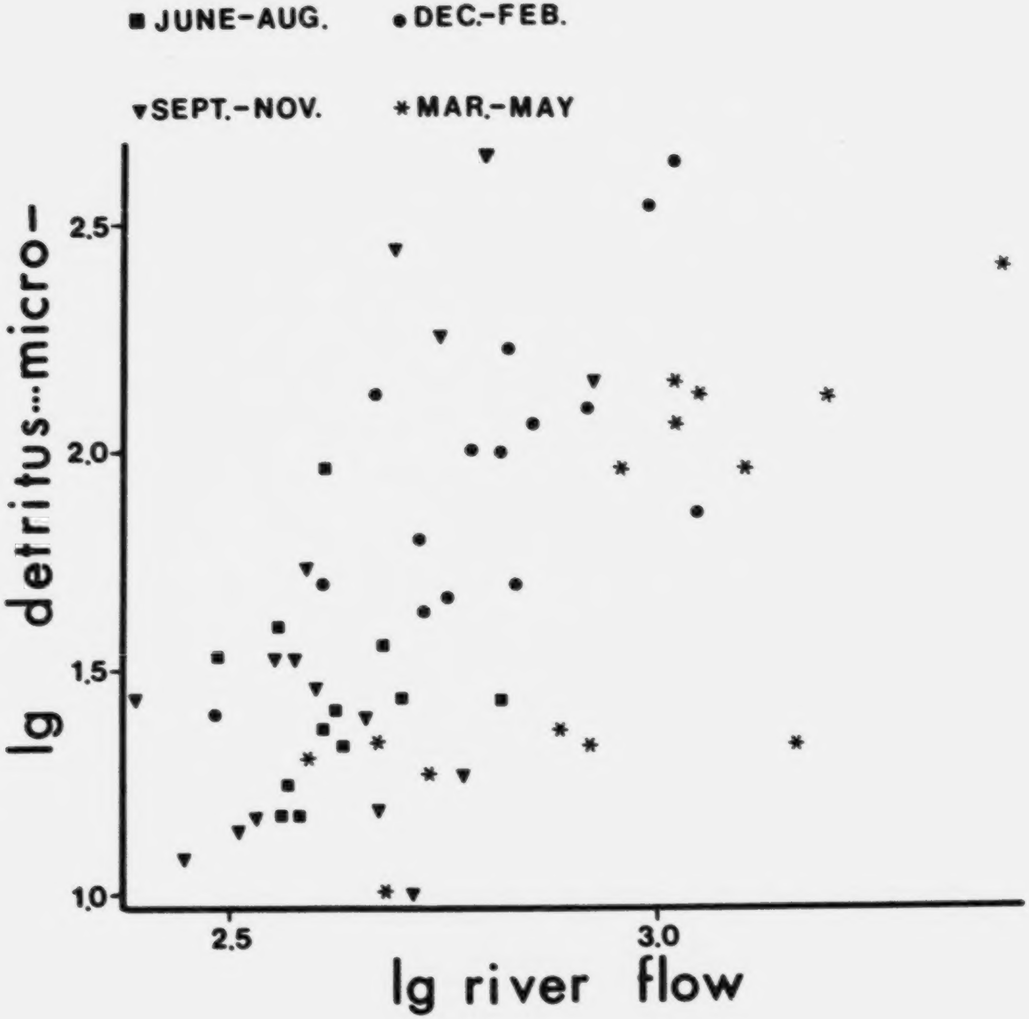

Figure 3. Regression analysis (log/log) of the relationship of microdetritus (totals taken from station 7, surface) to Apalachicola River flow by season.

direct correlation of river flow and detritus in the system. By the fall, there is still no significant relationship although there are occasional influxes of detritus with minor peaks in the river flow. By winter, however, there is a strong direct relationship between microdetrital loading and river flow peaks. However, the winter regression differs from that of the spring detrital loading which, though significantly associated with river flow levels, requires higher river levels for comparable concentrations and loading of detritus. This analysis indicates that the degree and timing of river flooding on a seasonal basis affects the level of detrital loading to the estuary.

The key to the biological significance of the detrital flux into the estuary lies in the spatial/temporal response of the estuarine biota. Such a response is not easily determined because of the natural variability of the system. Livingston (1978) and White et al. (1979) have described the experimental basis for the detrital-based energy system in the Apalachicola estuary whereby organic particulate matter and dissolved nutrients are transformed into microbial biomass. Such energy is then utilized by a diverse macrofauna. Sheridan and Livingston (1979) and Laughlin and Livingston (in review) have detailed some key components of the food web structure in the Apalachicola estuary. The detrital input is an important part of the system. The timed reaction of the biological components to climatological features such as rainfall and river flow have also been established (Livingston et al. 1977; Livingston and Loucks, 1979). There are various indications that seasonal and annual variation of river input is an important factor in the estuarine response. The results of this study indicate that the qualitative and quantitative aspects of detrital input into the estuary are dependent on a number of factors that vary throughout a given season, and from year to year. While the important detrital food web is closely associated with the timing and degree of river flooding, functional relationships remain undetermined and are currently under study. However, it is clear that, while the river is important with regard to bay productivity, such relationships depend to considerable degree on climatological conditions, trophic response, and the natural history of various estuarine species.

The data presented here are preliminary in that the biological response of the estuary remains dependent on various features of the estuarine habitat. Experimental studies are currently being carried out to determine the relationship of the estuarine food webs and community structure with potential biological-controlling features such as predation and competition. However, the results of this study indicate the importance of the specific timing (seasonal, annual) of climatological events relative to the quality and quantity of input of allochthonous detritus which moves into the estuary. Periodic (pulsed) movement of detritus is only one part of the biologically important features of habitat organization. A knowledge of the details of biological response to such environmental variables will be necessary if we are to understand the impact of anthropogenic alteration of the timing and extent of river flow on receiving estuarine systems.

LITERATURE CITED

de la Cruz, A.A. Production and transport of detritus in wetlands. Paper presented at the National Wetland Symposium. Disneyworld Village, Lake Buena Vista, Florida; 1978 November 7-10; 1979.

de la Cruz, A.A.; Post, H.A. Production and transport of organic matter in a woodland stream. Arch. Hydrobiol. 20:227-238; 1977.

Haines, E.B. Interactions between Georgia salt marshes and coastal waters: a changing paradigm. Livingston, R.J., ed. Ecological processes in coastal and marine systems. New York: Plenum Press; 1979: 35-46.

Hynes, H.B.N.; Kaushik, N.K.; Lock, M.A.; Luch, D.L.; Stocker, Z.S.J.; Wallace, R.R.; Williams, D.D. Benthos and allochthonous organic matter in streams. J. Fish. Res. Board Can. 31:545-553; 1974.

Kaushik, N.K.; Hynes, H.B.N. The fate of the dead leaves that fall into streams. Arch. Hydrobiol. 68:465-515; 1971.

Laughlin, R.A.; Livingston, R.J. Spatial/temporal variability in the distribution of the blue crab (*Callinectes sapidus*) in a north Florida estuary (in review).

Livingston, R.J. Effects of forestry operations (clearing, draining) on water quality and biota of the Apalachicola Bay system. Florida Sea Grant, Final Report; 1978; 400 pp.

Livingston, R.J.; Duncan, J. Short- and long-term effects of forestry operations on water quality and epibenthic assemblages of a north Florida estuary. Livingston, R.J., ed. Ecological processes in coastal and marine systems. New York: Plenum Press; 1979: 339-381.

Livingston, R.J.; Loucks, O. Productivity, trophic interactions, and food web relationships in wetlands and associated systems. Paper presented at the National Wetlands Symposium. Disneyworld Village, Lake Buena Vista, Florida; 1978 November 7-10; 1979:101-119.

Livingston, R.J.; Iverson, R.L.; White, D.C. Energy relationships and the productivity of Apalachicola Bay. Florida Sea Grant Program, National Oceanic and Atmospheric Administration (Final Report); 1976: 437 p.

Livingston, R.J.; Sheridan, J.S.; McLane, B.G.; Lewis, F.G., III; Kobylinski, G.G. The biota of the Apalachicola Bay system: functional relationships. Livingston, R.J.; Joyce, E.A., Jr., eds. Proceedings of the Conference on the Apalachicola Drainage System. Gainesville, Florida; 1976 April 23-24. Florida Department of Natural Resources, Mar. Res. Lab. Contr. #26; 1977: 75-100.

Meeter, D.A.; Livingston, R.J.; Woodsum, G. Short- and long-term hydrological cycles of the Apalachicola drainage system with application to gulf coastal populations. Livingston, R.J., ed. Ecological processes in coastal and marine systems. New York: Plenum Press; 1979: 315-338.

Odum, W.E.; Fisher, J.S.; Pickral, J.C. Factors controlling the flux of particulate organic carbon from estuarine wetlands. Livingston, R.J., ed. Ecological processes in coastal and marine systems. New York: Plenum Press; 1979: 69-80.

Post, H.A.; de la Cruz, A.A. Litterfall, litter decomposition, and flux of particulate organic material in a coastal plain stream. Hydrobiologia 55:201-207; 1977.

Sheridan, P.; Livingston, R.J. Cyclic trophic relationships of fishes in an unpolluted, river-dominated estuary in north Florida. Livingston, R.J., ed. Ecological processes in coastal and marine systems. New York, Plenum Press; 1979: 143-161.

White, D.C.; Livingston, R.J.; Bobbie, R.J.; Nickels, J.S. Effects of surface composition, water column chemistry, and time of exposure on the composition of the detrital microflora and associated macrofauna in Apalachicola Bay, Florida. Livingston, R.J., ed. Ecological processes in coastal and marine systems. New York: Plenum Press; 1979: 83-116.

DISCUSSION

Question: What are the implications for water release in the Woodruff Dam?

Answer: The Woodruff Dam is actually a flow-through system. They don't have a storage capacity. During the winter time it flows at the normal actual river flow. In fact, we modeled the river before and after and there is no difference in flow. The only difference has to do with the freshwater fishing along the river. During the low summer flows, I can tell you when everybody is turning their air conditioners on, because you've got big six-foot waves going down the river which are destroying the habitat of freshwater fishes which are trying to reproduce at that time. I would say that the only control would be relatively minor and possibly not even allowed because they have a certain legal amount of water that has to go over that dam. The only way they could help the situation is in the summer flows by not running it in at times when the freshwater fishes are trying to reproduce.

Question: There's not a hydroelectric generator, is there?

Answer: Yes, there is.

Question: The only release of water that takes place in the summer is through the hydroelectric reserve?

Answer: Well, it goes through the hydroelectric system, yes, and they are generating electricity. You can watch the peak on weekends.

Question: If you could conceive that some kind of water regulation could take place on that river, what would you ask for?

Answer: We've got other problems that are more pressing than regulation, I think. One would be the actual allowance that the river be kept running. It has been projected that by 2005 the Atlanta area will have grown to such a size that we're not going to have any more flow out of the Chatahoochee which is one of the main parts of that system. That would mean that we're all going to be struggling for water. I have heard other papers that are telling the same thing. If there's one thing at this conference that has to be faced, it is that within the next thirty years we might not be getting any more flows that we're showing here. Certainly, these peaks are going to be knocked off that river. There's no doubt that they're going to be able to store enough water there for use, so that you're not going to be getting this peak anymore. This system is going to change. I think we can start to predict how it's going to change by recognizing the relationships we've got right now. As far as controlling the dam, I really don't think that's going to help much at this particular point.

Question: There's one more point. With the effect of the dam do you basically have higher lows and lower highs?

Answer: We've done a hydroelectric record on pre-dam and post-dam flows, and we cannot detect any serious changes in peaking except for minor changes in summer lows and perhaps, somewhat lower highs.

Question: So, you've got a general raising of the lows and lowering of the peaks but it's not something real drastic?

Answer: The Army Corps of Engineers predicted that the closer they get to the bay with the dams, the more winter peaks will be lowered.

Question: Generally, what do you want out of that river?

Answer: I'll tell you what I want. I want to leave this system alone. I want it to work like it has always worked. I'll tell you why. It's one of the last functional systems we've got. Most of the other systems I've gone over have either been dammed or there's agriculture or pollutants or something else in the river. We can't find any pollutants here, and the river's still flooding. We've still got tremendous productivity. I'd like to see it all stay the same and study it and find out how it goes, and, then, I can help out, perhaps, in the Chesapeake where they don't have such base-line data. It is critical to have base-line data to see how the system functions because when you put man in these systems you change the system. The orchestra's not playing the same tune and it isn't predictable. Or, maybe it's too predictable. This is a national estuarine sanctuary. This is the largest, most ambitious estuarine sanctuary in the country. Eight percent of the people in this system would like to keep the system the way it is. That's another point. We've done a lot of work with educating these people on how this works by going into schools, by going on radio and TV, and presenting the scientific data to the public.

Question: That's 2,000 square miles of your watershed. What about the other people up in Georgia and Alabama?

Answer: I'll be quite honest with you. There's some people up there who have said this is going to be the next Ruhr valley of the south. They want to dam it and make this a major channel for industrialization. I don't think that should go on. I think it should still be a multiuse system. They can use it, but they don't destroy it for other people.

Question: If there's a mechanism to get scientific data, can you get it in the hands of the right people to use it? I think that should be a question answered at this conference.

Answer: Don't you think that's due partly to the fact that working on estuaries falls between the responsibilities of all the agencies?

Question: It's doesn't escape all the agencies. I think it is a very valid question to ask. It's quite simply, yes, for us today. You talk about flows to the estuary determined by places like Atlanta and the institutional interface is through agencies such as HUD, which provides grants for permissions to construct new housing developments and this type of thing. We have very weak methodology to input into that process. I'm from Galveston, Texas, now, and we're trying to deal with that question in the Houston area. So far it's a very slow battle. Furthermore, we don't even really know what we're trying to accomplish there.

Answer: I think Bob Herbst touched on that, and I'd like to emphasize that the worst enemy we've had as far as constructing a system has been the Federal Government. Not just the Federal Government, but the Congress of the United States with the various edicts they have made over the years. Keeping that a deep channel has shown over one-half billion dollars for navigation alone. The flood plain insurance program actually encourages people to settle all through some of these sensitive flood plain areas and along our barrier islands which is another rather sensitive area.

They build bridges with federal funds out to our barrier islands. The last data I was showing you were purchased and actually paid for by the fishermen in Franklin County, because I've not been able to get any sustained federal funding for any of this research. The one sustained group that has funded me has been a county that is considered to have the poorest per capita income in the state. I think our worst enemies are right here in Washington, D.C.

Question: How do you propose to stop or slow down the influx of people to Florida?

Answer: I don't want to slow them down. I want to put them in the right places. You could put a lot of people in that valley and not affect a thing.

Question: You talk like it's up to the county commissions to regulate what happens.

Answer: The point is though, I'm not trying to make it overly simple. There are outside agencies that are working, and there are also laws. These laws apply to these systems. If you have enough information on how this system works it makes it a little more difficult to destroy the system. I don't say it won't be destroyed. You can make it difficult if you have the answers already in the scientific literature. We're winning cases. They won that Red River thing because he had some information and it was bought by the court. But you can't go in and say, "I'm an environmentalist, and I love this system, and I want it to go on the way it is." Or "I'm so and so from the Fish and Wildlife Service, and I'm a big man in Washington, and I want this system to stay the way it is. You can't do that. It doesn't work that way.

Question: You've got a lot of answers on the upper Apalachacola and I'm impressed. How can you translate that into instruction or direction at the decision level in the remote area if it's affecting your particular aspect of the system? That's the problem we're facing. I had to go out and talk to HUD and tell HUD what I want.

Answer: Each group has to solve that problem separately because each situation is different. In our area we have established an estuarine sanctuary there. Through the sanctuary, we're now going to get new programs. We're going to apply them all the way up to Atlanta and make sure that the people all along that tri-river system know what's going on.

CHAPTER 5

MISSISSIPPI RIVER DELTA FRESHWATER INFLOW REHABILITATION

FLOW REGIME AND SEDIMENT LOAD AFFECTED BY ALTERATIONS OF THE MISSISSIPPI RIVER

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ABSTRACT

The Mississippi River drainage basin includes all or part of 31 states and 2 Canadian Provinces covering about 41 percent of the contiguous United States. The shape of the basin is much like a funnel with the spout entering the Gulf of Mexico in the State of Louisiana.

Over the past several thousand years the Mississippi River has occupied and abandoned seven deltas resulting in progradation of the shoreline and development of a large low-relief deltaic plain in south Louisiana. In its natural state, the river channel and its vast floodplain were used to convey all flows southward to the Gulf of Mexico following natural drainage patterns evolved over centuries of meandering by the river. Man's occupation of the valley brought with it extensive modifications to the river and its floodplain. These modifications, which made it possible for man to survive and prosper in the valley, have changed the distribution of water and sediment in distributaries and major outlets entering the estuaries.

Distribution of flow to the coastal area of south Louisiana has changed significantly over the past 140 years. A massive log raft removed by the State of Louisiana from the Atchafalaya River in the middle 1800's and subsequent natural enlargement, hastened by flood control and navigation works, has resulted in the Atchafalaya River, a major distributary of the Mississippi River, transporting about 25 percent of the discharge of the Mississippi. On the Mississippi, extension of flood protection levees resulted in closure of three distributaries above New Orleans and confined water and sediment to a well-defined leveed channel. In the Atchafalaya Basin, development of basin guide levees confined floods to a leveed floodway and two outlets, Atchafalaya River below Morgan City and Wax Lake Outlet.

In the past 30 years average suspended sediment loads in the Mississippi River Basin have been reduced about 50 percent. The natural process of sediment deposition in the Atchafalaya Basin has progressed from near the head of the Atchafalaya River in the late 1800's to Atchafalaya Bay, materially hastened by alterations in the basin. The middle reach of the Atchafalaya has experienced significant natural filling and

the formation of a new delta is occurring on the Louisiana coast approximately 77 miles west of the modern bird's-foot delta of the Mississippi.

INTRODUCTION

All runoff from the large drainage basin of the Mississippi converges in south Louisiana and exits into the Gulf of Mexico (Figure 1). Over the past 6,000 to 8,000 years the Mississippi River has occupied several positions (Figure 2) resulting in progradation of the shoreline and development of a large low-relief deltaic plain in south Louisiana (Fisk 1952). The Atchafalaya Basin, a large lowland bounded by the high natural levees of the Mississippi and Bayou Lafourche on the east and Bayou Teche on the west, is the most prominent feature in the Lower Valley (Figure 3). Within the Atchafalaya Basin, the Atchafalaya Floodway and Atchafalaya Bay are currently experiencing morphological changes on a grand scale (Figure 4).

Prior to the 1840's, the Mississippi was the primary route for delivery of water and sediments to the gulf. Discharges up to bankfull remained in the channel and exited into the gulf with the exception of minor percentages that diverted through distributaries. Discharges exceeding bankfull flowed generally southward through the Atchafalaya Basin lowlands and into the gulf through numerous bayous and outlets. Distribution of flow and sediment is significantly different today. The Atchafalaya River, a dynamic distributary of the Mississippi, has a distinct gradient advantage and is currently controlled to carry about 25 percent of the flow and sediment load of the Mississippi River. Flood flows now enter the Atchafalaya Basin in a controlled fashion, rather than through levee crevasses. Major natural distributaries, Bayou Manchac, Bayou Plaquemine, and Bayou Lafourche have been closed by flood protection levees. This paper describes the natural regime of the river, reviews alterations of the Mississippi River drainage system, and discusses their effect on the flow regime and sediment loads entering estuaries.

NATURAL DRAINAGE PATTERN OF SOUTHERN LOUISIANA

Estuaries of south Louisiana (Figure 5) can be divided into three zones: zone 1 lies east of the modern Mississippi River and its bird's-foot delta and includes Lakes Maurepas, Ponchartrain, and Breton Sound; zone 2 is bounded on the east by the Mississippi River and its delta and on west by the high natural ridges of the Lafourche system; and zone 3 is the broad Atchafalaya Basin bounded on the east by the Lafourche system and on the west by the natural higher levees of the former Teche delta system (Figure 2). In its natural state, distribution of water and sediment to estuaries in zone 1 was via Manchac Bayou, a distributary located about 15 miles downstream of Baton Rouge, Louisiana, to Lakes Maurepas, Ponchartrain, and Borgne, and Pass A Loutre at the mouth of the Mississippi River; in zone 2 via Bayou Lafourche, a distributary located at Donaldsonville, Louisiana, and southwest pass at the mouth of the Mississippi River; and in zone 3 via the Atchafalaya River and Bayou Plaquemine, a distributary located at Baton Rouge, Louisiana. The

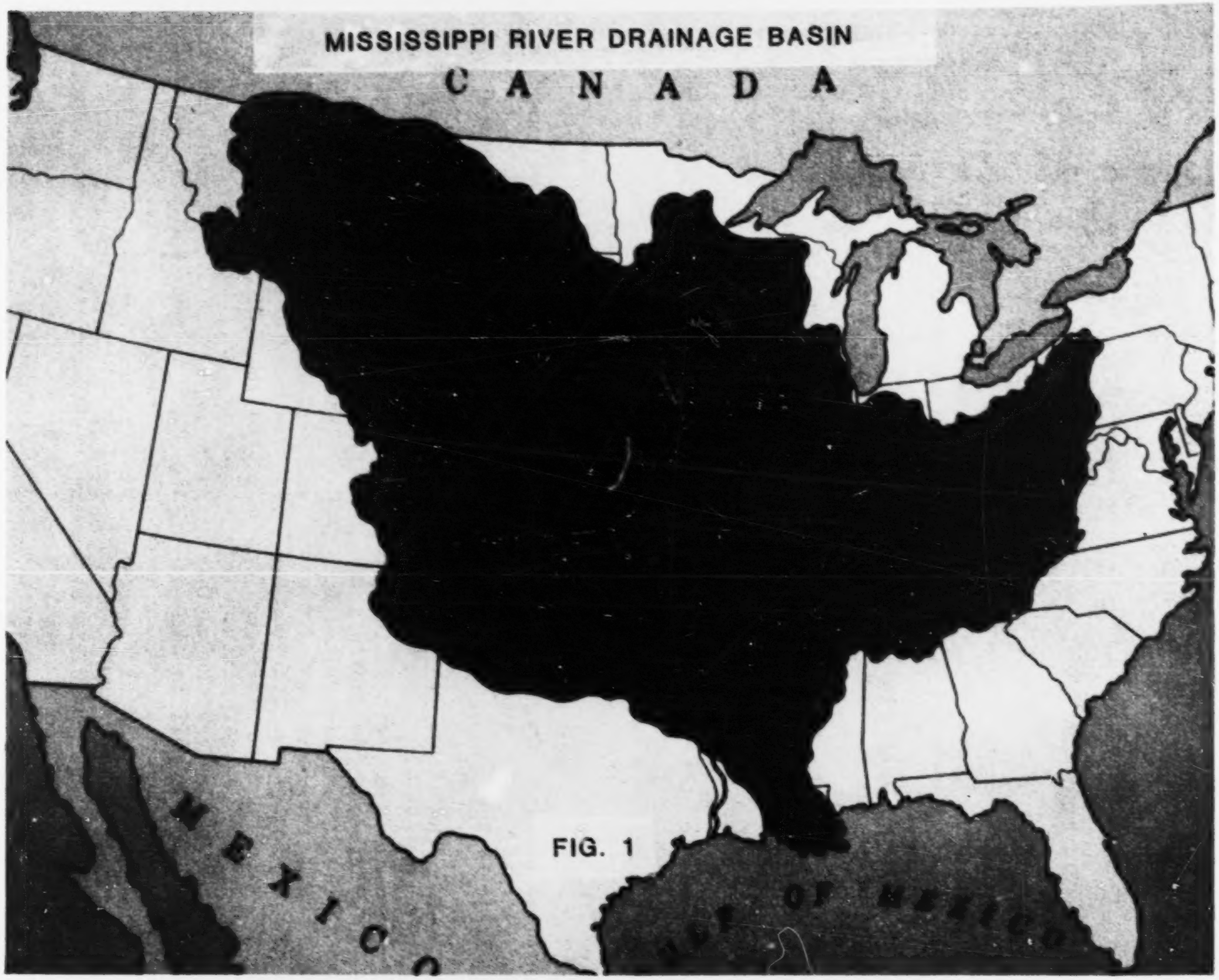

MISSISSIPPI RIVER DRAINAGE BASIN
CANADA
MEXICO
GULF OF MEXICO

FIG. 1

Figure 1. Mississippi River Drainage Basin.

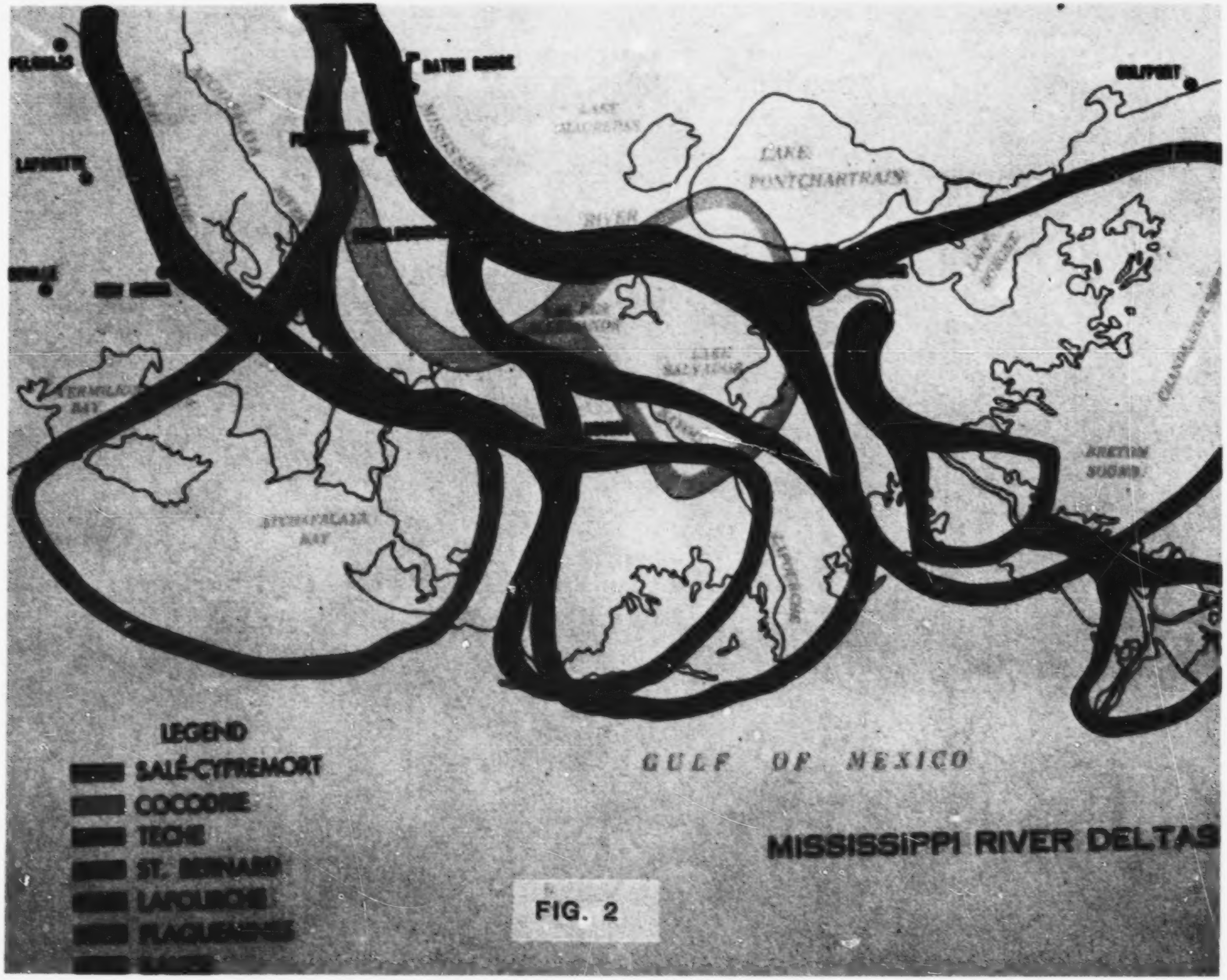

BATON ROUGE
GULFPORT
LAFAYETTE
LAKE MAUREPAS
LAKE PONTCHARTRAIN
MISSISSIPPI
RIVER
TECHE
LAKE BORGNE
LAKE SALVADOR
VERMILION BAY
ATCHAFALAYA BAY
BRETON SOUND
CHANDELEUR SOUND
GULF OF MEXICO
MISSISSIPPI RIVER DELTAS
LEGEND
SALÉ-CYPREMORT
COCODRIE
TECHE
ST. BERNARD
LAFOURCHE
PLAQUEMINES

FIG. 2

Figure 2. Mississippi River Deltas.

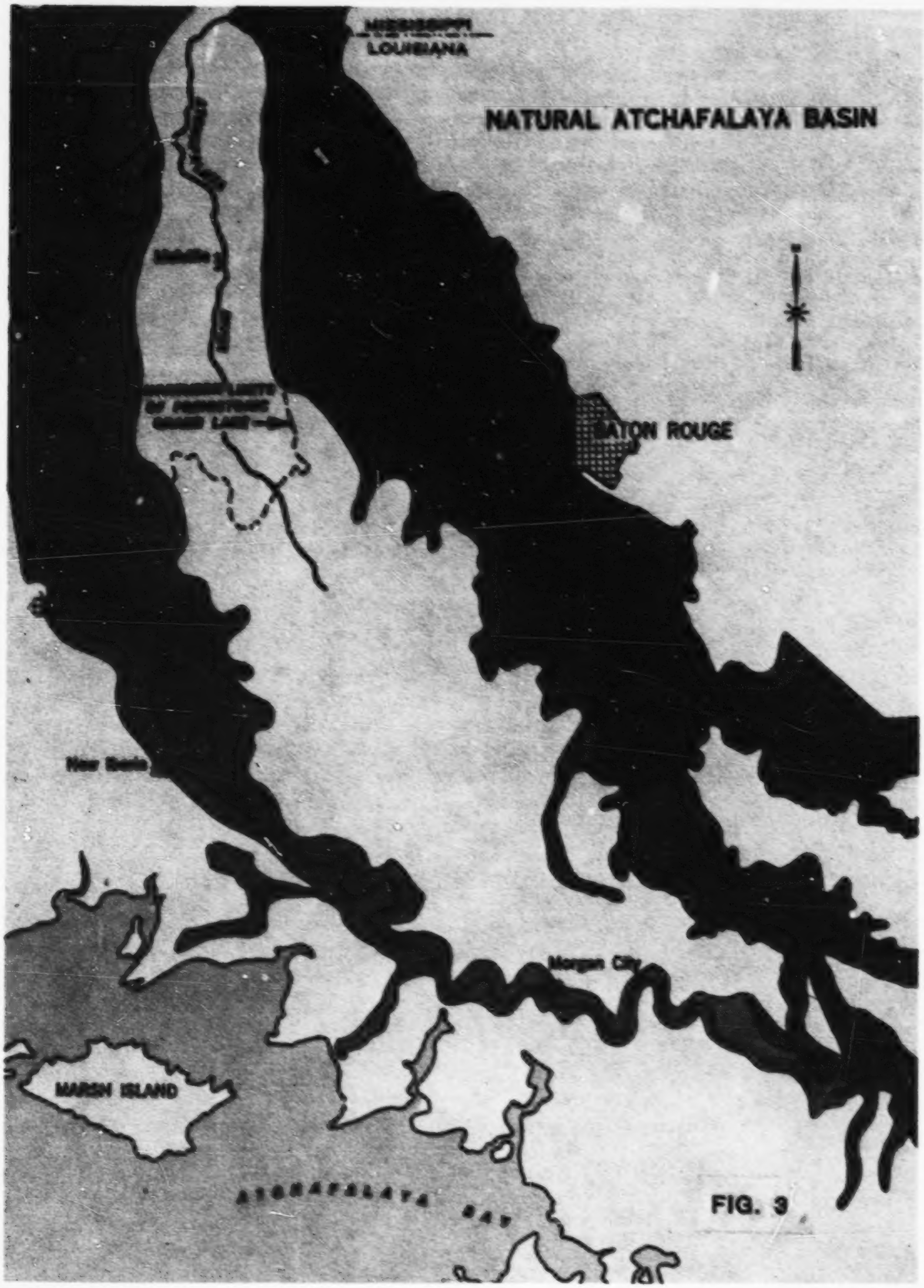

MISSISSIPPI
LOUISIANA
NATURAL ATCHAFALAYA BASIN
N
BATON ROUGE
New Iberia
Morgan City
MARSH ISLAND
ATCHAFALAYA BAY

FIG. 3

Figure 3. Natural Atchafalaya Basin.

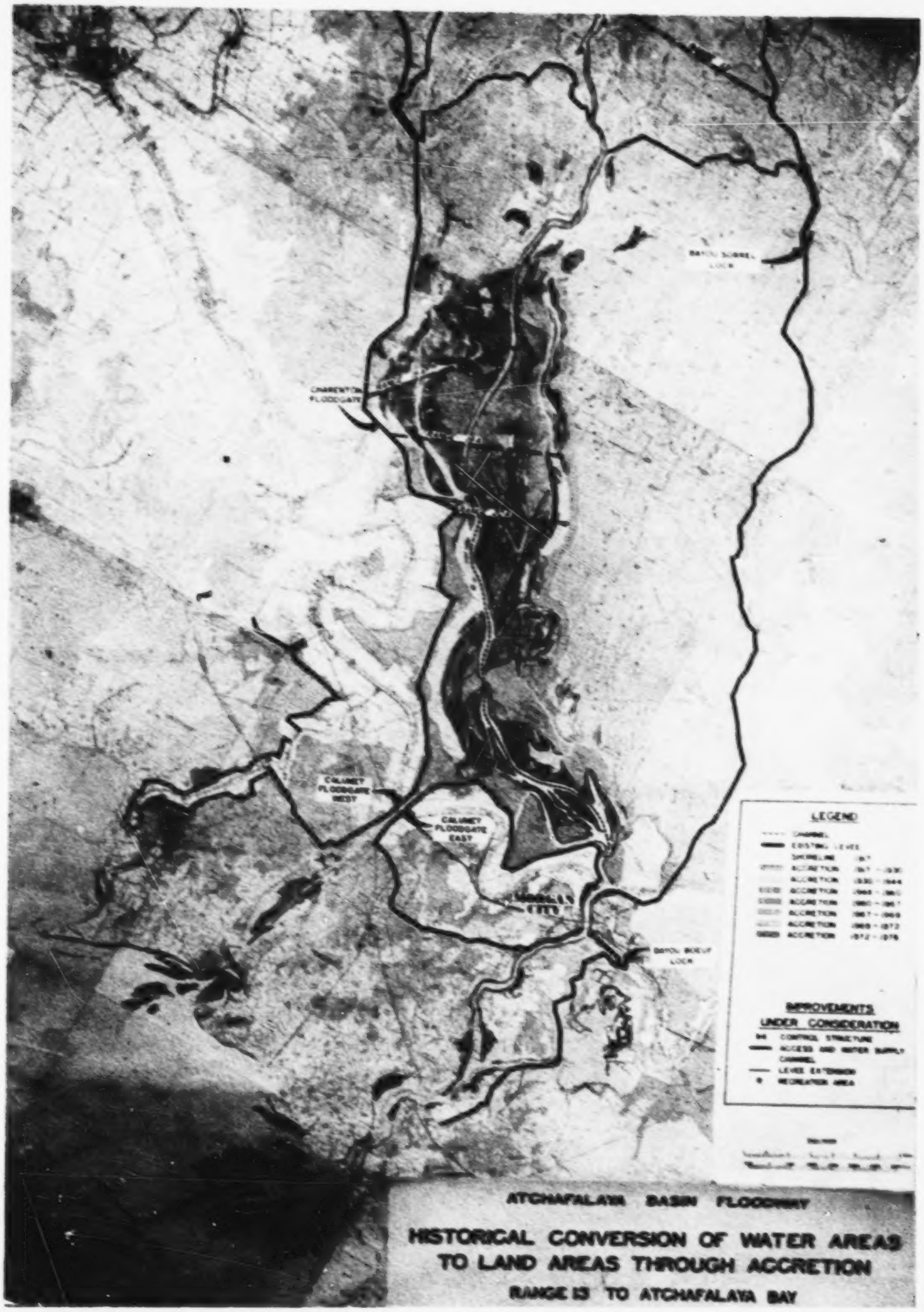

BAYOU SORREL LOCK
CHARENTON FLOODGATE
CALUMET FLOODGATE WEST
CALUMET FLOODGATE EAST
MORGAN CITY
BAYOU BOEUF LOCK
LEGEND
CHANNEL
EXISTING LEVEE
SHORELINE
ACCRETION
ACCRETION
ACCRETION
ACCRETION
ACCRETION
ACCRETION
ACCRETION
IMPROVEMENTS UNDER CONSIDERATION
CONTROL STRUCTURE
ACCESS AND WATER SUPPLY CHANNEL
LEVEE EXTENSION
RECREATION AREA
ATCHAFALAYA BASIN FLOODWAY
HISTORICAL CONVERSION OF WATER AREAS TO LAND AREAS THROUGH ACCRETION
RANGE 13 TO ATCHAFALAYA BAY

Figure 4. Atchafalaya Basin Floodway.

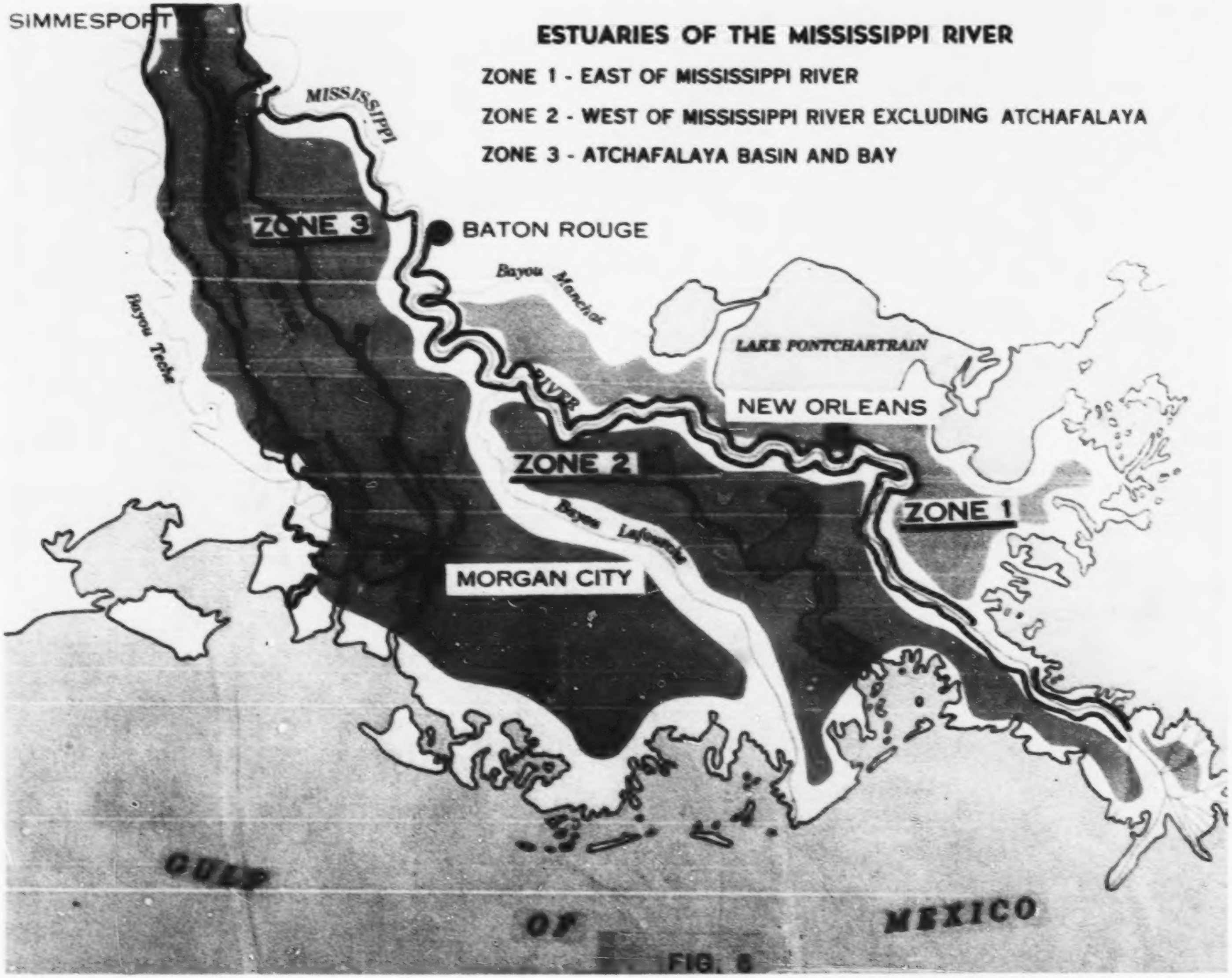

ESTUARIES OF THE MISSISSIPPI RIVER
ZONE 1 - EAST OF MISSISSIPPI RIVER
ZONE 2 - WEST OF MISSISSIPPI RIVER EXCLUDING ATCHAFALAYA
ZONE 3 - ATCHAFALAYA BASIN AND BAY
SIMMESPORT
MISSISSIPPI
ZONE 3
BATON ROUGE
Bayou Manchac
Bayou Teche
LAKE PONTCHARTRAIN
RIVER
NEW ORLEANS
ZONE 2
ZONE 1
Bayou Lafourche
MORGAN CITY
GULF
OF
MEXICO
FIG. 8

Figure 5. Estuaries of the Mississippi River.

distribution system was periodically supplemented during high flows by various crevasses and breaks in the natural and later man-made levee systems of the lower Red and Mississippi rivers (Elliott 1932).

NATURAL FLOW REGIME

For discharges up to bankfull the Mississippi River and four major distributaries, delivered flow to the estuaries. Estimated bankfull capacity of the Mississippi River in 1851 was about 1,000,000 cfs. The combined peak discharge of Bayous Plaquemine and Lafourche in the 1858 flood was 45,000 cubic feet per second (cfs), with the peak of Bayou Plaquemine being three times greater than Bayou Lafourche. No measurements were available for Bayou Manchac or Atchafalaya River, however, based on early descriptions, Bayou Manchac had less capacity than Bayou Lafourche and the Atchafalaya River was choked by a massive log raft probably rendering it ineffective except during flood overflow. In times of flood, the Atchafalaya Basin (zone 3) served as the major outlet for excess flood waters. Flows entered the Basin by overtopping banks, through the Atchafalaya River and Bayou Plaquemine with some contribution from Bayou Lafourche, and through crevasses in natural levees on the west bank of the Mississippi from Red River Landing, Louisiana, to Donaldsonville, Louisiana. Zone 1 and zone 2 received excess flood water through crevassing of natural levees which occurred frequently but not necessarily in every flood.

NATURAL SEDIMENT DISTRIBUTION

There is no reliable data upon which to make a determination of the magnitude of sediment loads transported by the Mississippi River in its natural state. Measurements of suspended sediment were taken in the 1800's at various locations on the river; however, the equipment used and the random sampling procedures followed make the results of those measurements of little practical use (Paper H 1930). It is assumed that the distribution of sediments was about in proportion to the distribution of flows previously described. It is very probable that only a minor portion of the sediment loads entered distributaries, and that accompanying excess flood flows ever reached the vicinity of the coastline due to the low topographical features of zones 1, 2, and 3.

ALTERATIONS OF THE MISSISSIPPI

In recent history numerous alterations of the Mississippi have been accomplished, each designed to fulfill a specific objective and necessary for man to continue to survive and prosper in the Mississippi River Valley. Not all alterations affect the flow regime and sediment load of the river, at least not significantly, and some alterations affect only the distribution (the route of discharge and sediment) rather than the magnitude of discharge and sediment loads. Those alterations considered significant include: levees, reservoirs, bank stabilization, and removal of Atchafalaya River log raft.

LEVEES

The primary effect of levees on flow regime and sediment loads entering estuaries has been confinement of discharges and sediment loads to three specific all stage outlets: Head of Passes and vicinity; Atchafalaya River, south of Morgan City, Louisiana; and Wax Lake Outlet, west of Berwick Bay, Louisiana and one flood relief spillway, Bonnet Carre Spillway located just north of New Orleans, Louisiana (Figure 6). Levee extensions closed Bayous Manchac, Plaquemine, and Lafourche in 1828, 1866-1867, and 1903, respectively.

BANK STABILIZATION

It has been estimated that caving banks in the lower Mississippi River, prior to stabilization, yielded annually about 1,000,000 cubic yards of material per mile of river (Shen 1971). The program of bank stabilization in the lower Mississippi River steming from the 1928 Flood Control Act is about 76 percent complete. Recently, estimated volumes of material caving into the river annually in the Vicksburg District, are a fraction of the previous estimate, therefore, revetments are probably responsible for a substantial portion of the reductions in suspended sediment loads experienced on the Mississippi River and tributaries.

RESERVOIR REGULATION

Over the past 50 years several hundred single and multipurpose reservoirs have been constructed in the headwaters of the major tributaries of the Mississippi. Currently these reservoirs control the runoff from about 58 percent of the basin area. Reservoirs trap large percentages of incoming sediment loads, therefore, it is possible that reservoirs have influenced reduction of suspended sediment loads on the Mississippi.

REMOVAL OF ATCHAFALAYA RIVER LOG RAFT

In 1831 Captain Shreve made a cutoff in the Mississippi River across the neck of Turnbull Island (to aid navigation) which left the mouth of the Red River and the head of the Atchafalaya River in an oxbow lake with a two-way connection to the Mississippi River (Figure 7). The Atchafalaya, at this time, was an ineffective distributary of the Mississippi, choked by a massive log raft covering 20 miles of its length. A few years after Shreve's cut off, local interest, and later the State of Louisaina, undertook removal of the raft for the purpose of developing navigation on the Atchafalaya. Their efforts were eventually successful and the Atchafalaya was reportedly open by 1855 (Latimer 1951). Because of a distinct gradient advantage, the Atchafalaya enlarged rapidly near its mouth causing lands previously exempt from overflow to be submerged annually by the increasing volume from above. Local interest responded by building levees, confining flows, and closing outlet channels, causing the Atchafalaya to scour its bed, thus, hastening the inevitable natural enlargement of the river. While the upper Atchafalaya was rapidly enlarging, the middle and lower reaches of the Atchafalaya Basin were experiencing rapid and excessive sedimentation, signaling the beginning of a deltaic process. In 1932 efforts to hasten the development of an efficient well-defined single channel through the deteriorating reach were undertaken. The present channel is a culmination of those efforts.

Figure 6.

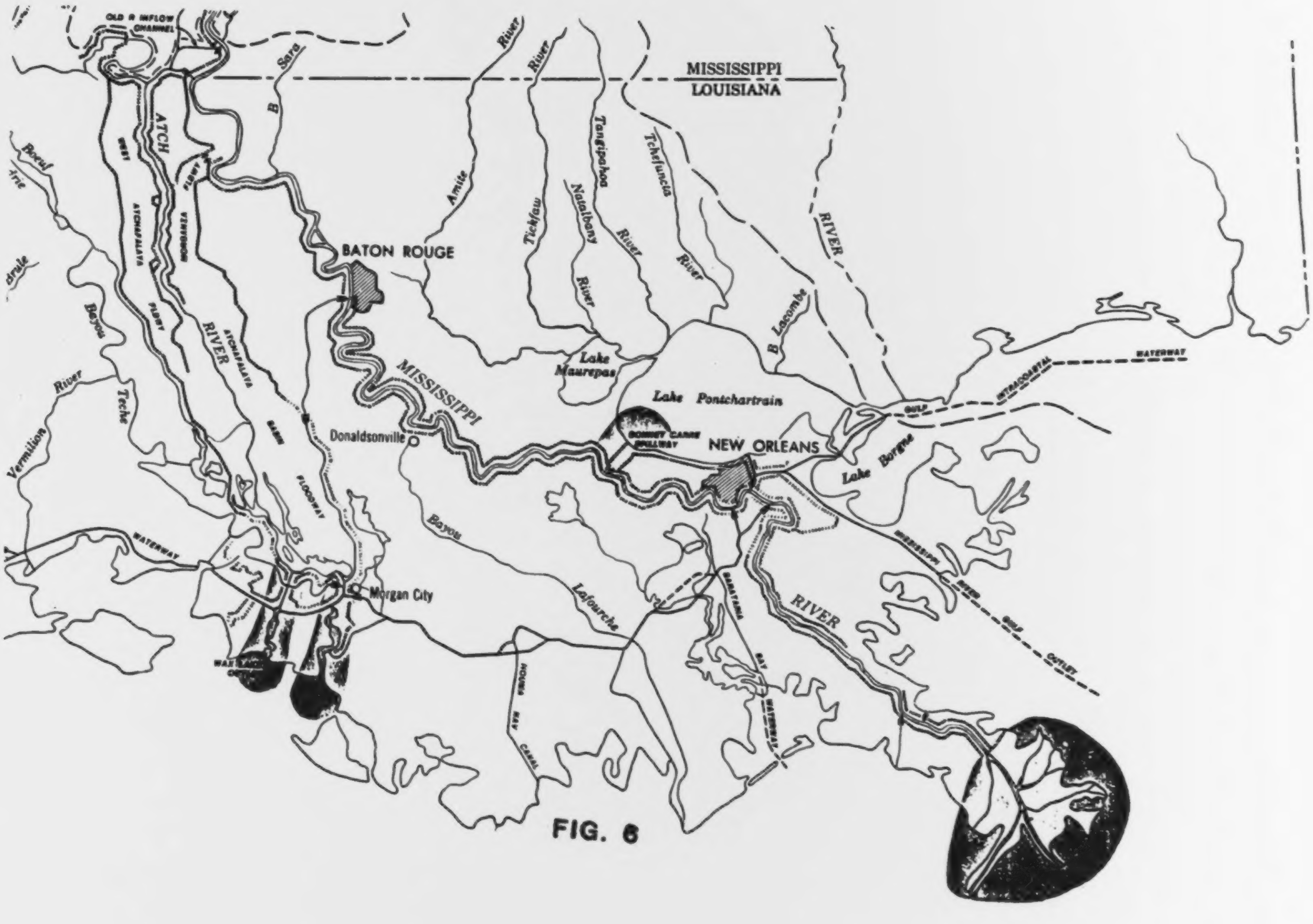
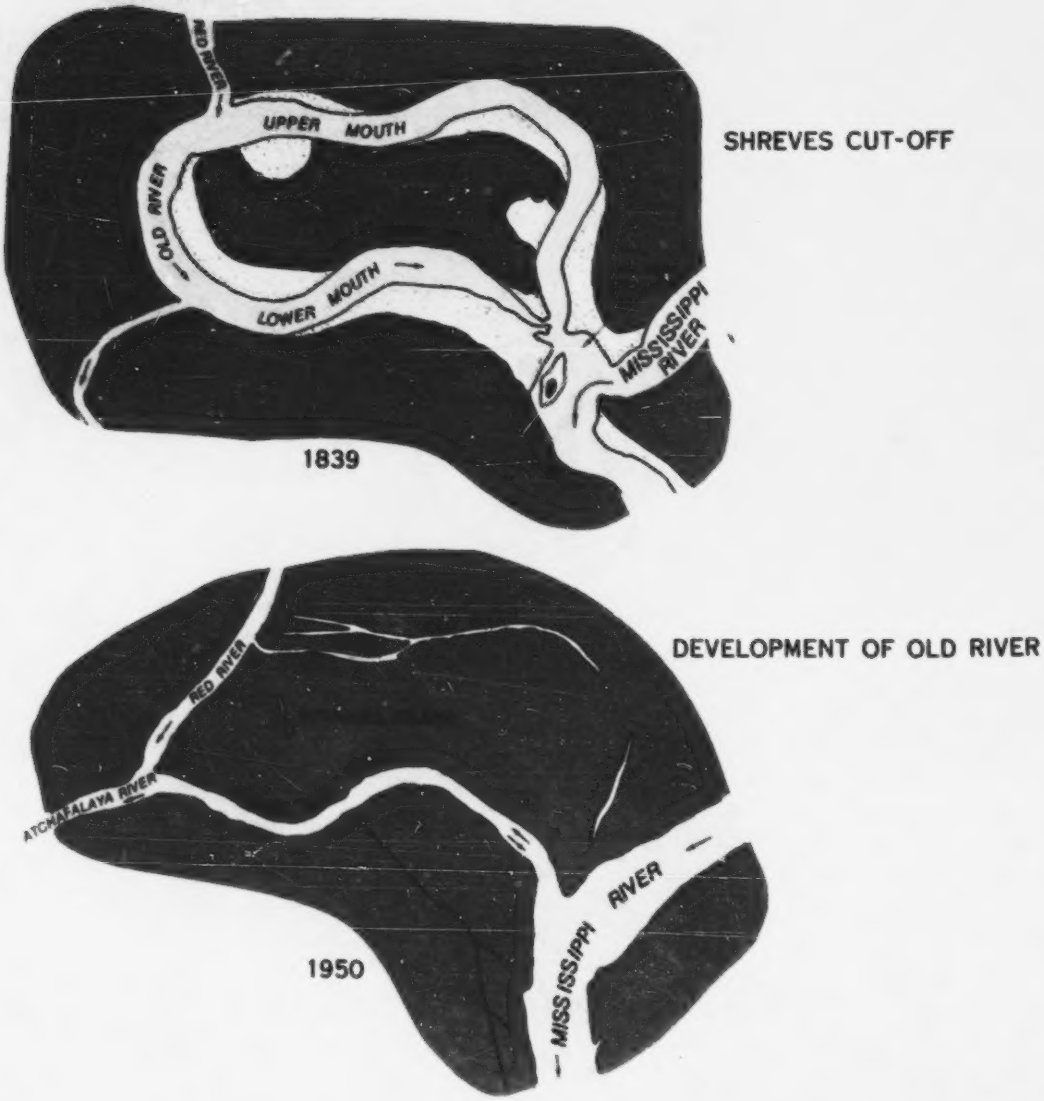

OLD R INFLOW CHANNEL
MISSISSIPPI
LOUISIANA
B Sara
ATCH
WEST ATCHAFALAYA FLOODWAY
ATCHAFALAYA RIVER
ATCHAFALAYA BASIN FLOODWAY
Boeuf
Bayou Teche
Vermilion River
Amite River
Tickfaw
Natalbany River
Tangipahoa River
Tchefuncta River
B Lacombe
PEARL RIVER
BATON ROUGE
Lake Maurepas
Lake Pontchartrain
MISSISSIPPI
Donaldsonville
BONNET CARRE SPILLWAY
NEW ORLEANS
Lake Borgne
GULF INTRACOASTAL WATERWAY
WATERWAY
MISSISSIPPI RIVER GULF OUTLET
Bayou Lafourche
Morgan City
WAX LAKE OUTLET
HOUMA NAV CANAL
BARATARIA BAY WATERWAY
RIVER

FIG. 6


RED RIVER
UPPER MOUTH
OLD RIVER
LOWER MOUTH
MISSISSIPPI RIVER
1839
RED RIVER
ATCHAFALAYA RIVER
MISSISSIPPI RIVER
1950

SHREVES CUT-OFF

DEVELOPMENT OF OLD RIVER

FIG. 7

Figure 7. Shreves Cut-Off.

Development of the Atchafalaya Floodway levees system was undertaken in 1932, which confined flow to about 50 percent of the original floodplain width from the leveed Atchafalaya River to just above Morgan City Reach.

In 1942 work was undertaken to construct a channel through Teche Ridge for the purpose of diverting 20 percent of the Atchafalaya flow to western Atchafalaya Bay. Subsequent, natural enlargement has increased the diversion to about 30 percent of the Atchafalaya flow.

EFFECT OF ALTERATIONS ON FLOW REGIME AND SEDIMENT LOADS

FLOW REGIME

Alterations of the Mississippi River, its drainage basin, and adjacent floodplain have been extensive, but, the effect of these alterations has been distribution of flow rather than influence on the annual volume of flow delivered to the estuaries. Removal of the Atchafalaya River log raft and subsequent alterations which hastened the natural enlargement process have resulted in the Atchafalaya River now carrying 30 percent of the total latitude flow of the Mississippi under normal conditions (Figure 8). This includes all of the Red River and portions of the Mississippi.

Levees have closed distributaries and confined flood flows of the Mississippi River drainage system to three all-stage outlets and one high-level outlet. The all-stage outlets are Head of Passes, south of New Orleans, Louisiana; Atchafalaya Bay, south of Morgan City, Louisiana; and Atchafalaya Bay, west of Morgan City, Louisiana.

The present distribution of flow to coastal Louisiana is 70 percent at Head of Passes; 21 percent, Atchafalaya Bay, south of Morgan City; and 9 percent, Atchafalaya Bay, west of Morgan City. The high-level outlet, Bonnet Carre Spillway, diverts flood flows in excess of 1,250,000 cfs to Lake Ponchartrain. This outlet has been operated six times, 1937, 1945, 1950, 1973, 1975, and 1979.

In summary, alterations have reduced flows in the Mississippi, increased flows in the Atchafalaya, closed three distributaries, and confined flows to three all-stage outlets and one high-level-flood outlet.

SEDIMENT LOADS

At the latitude of Red River Landing, Louisiana, sediment data have been collected at the following stations: Red River Landing, Louisiana, (September 1949 to date); Simmesport, Louisiana (September 1951 to date); Morgan City, Louisiana (1965 to date); and Wax Lake Outlet, Louisiana (1965 to date). The data consist of suspended sediment measurements which measure that portion of sediment load that is suspended in the water from the water surface to about 3 feet above the riverbed.

The measurements at Red River Landing represent the sediment loads transported by the Mississippi. The average annual load at this station for the period 1950-1959 was 307 million tons for an average annual volume of flow of 332 million acre-feet. For an equivalent volume of flow the average annual load for the period 1966-1976 was 170 million

FIG. 8

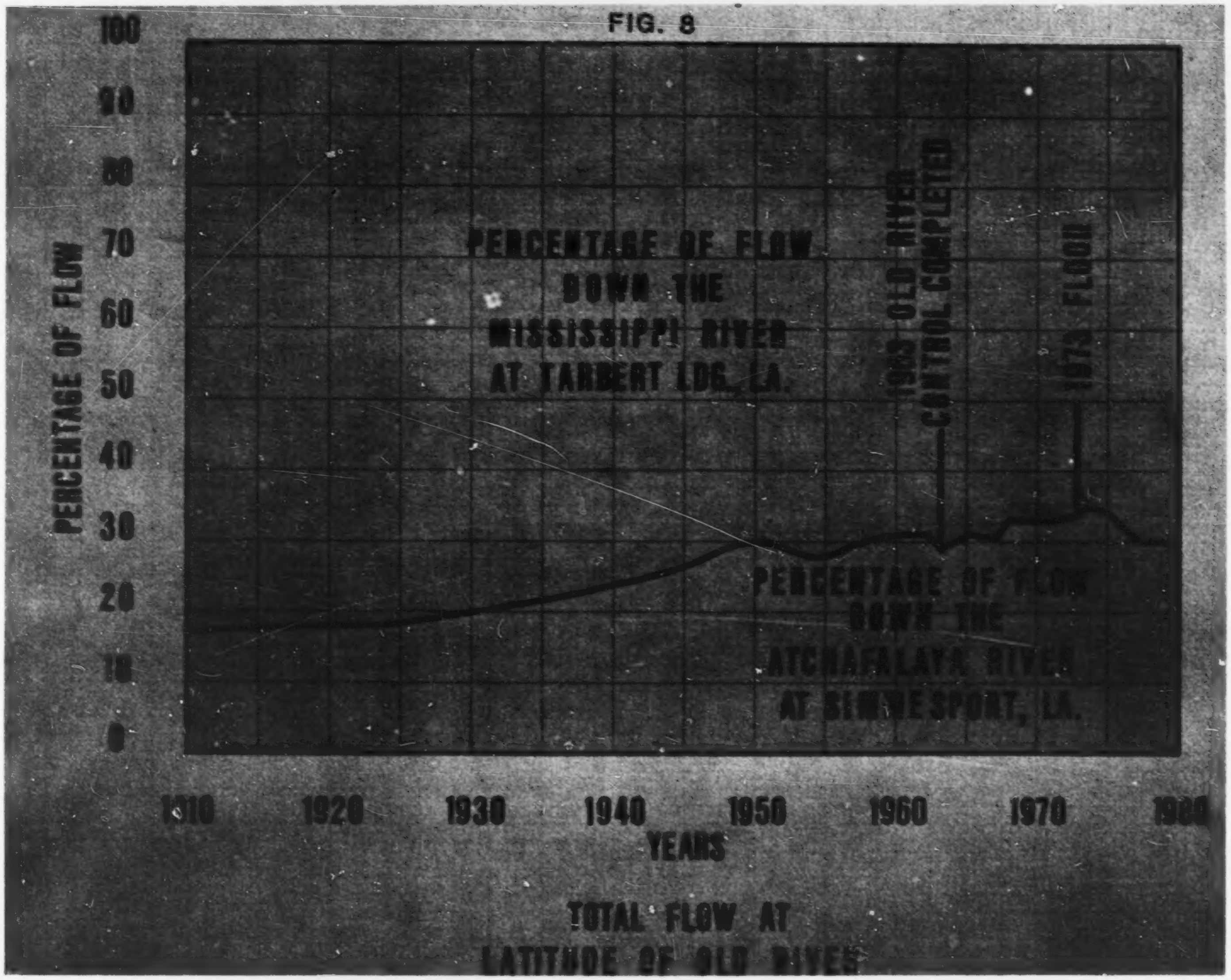


Figure 8. Distribution of Flow.

tons, a reduction of about 50 percent. At Simmesport, Louisiana, on the Atchafalaya River the average annual sediment load for the period (1951-1959) was 134 million tons for an average annual volume of flow of 122 million acre-feet. For an equivalent volume of flow, the average annual load for the period (1966-1976) was 70 million tons, a reduction of about 50 percent. Based on records available, channel stabilization and other features have reduced average annual suspended sediment loads delivered to south Louisiana by 50 percent.

The Atchafalaya Basin is unique and very complex relative to sediment loads and distribution. As previously mentioned, removal of the raft at the head of the fledgling Atchafalaya initiated the natural developments of that stream as a major distributary of the Mississippi. As scour enlarged the upper channel, rapid sedimentation took place in the middle reach of the basin. Development of a reasonably well-defined channel in the middle reach (1932-1968) decreased the rate of sedimentation in that reach, causing more sediments to be transported to Atchafalaya Bay.

By the 1950's significant influx of sediments to the Atchafalaya Bay begin to occur (Roberts et al. 1980) indicating that it took approximately 100 years for the initial channel development to push through to the coast of Louisiana, even though the process was materially hastened by alterations in the basin. Since 1950 the influx of sediment to the bay has increased dramatically. The reference cited above indicated that for the period 1973-1975 only 17 percent of the total average annual suspended sediment was retained in the Atchafalaya Basin with 65 percent carried by the lower Atchafalaya River and 19 percent carried by Wax Lake Outlet, resulting in the rapid filling of Atchafalaya Bay.

SUMMARY AND CONCLUSIONS

Under natural conditions water and sediment, contained within the channel and including the Red River which was a tributary of the Mississippi, flowed to the gulf by way of the Mississippi River and four primary distributaries: Bayou Manchac, Bayou Plaquemine, Bayou Lafourche, and the Atchafalaya River. In time of flood, excess water and sediment flowed from the Mississippi and Red Rivers southward to and through numerous bayous into the lakes and swamps along the coastline of Louisiana.

Alterations of the Mississippi and Atchafalaya Rivers over the past 140 years have significantly affected the distribution of flow and sediment loads entering the estuaries of south Louisiana. The most significant alterations were: removal of the Atchafalaya River log raft and subsequent alterations which hastened natural processes; confinement of flood flows by levees limiting discharges to three specific outlets; and those alterations that affected a 50 percent reduction in average annual suspended sediment loads transported by the Mississippi and Atchafalaya rivers.

Review of alterations and their affect on flow regime and sediment loads entering estuaries has led to the following conclusions:

a. The average volume of flow delivered annually to south Louisiana has not been affected by alterations.

b. The total (Mississippi plus Atchafalaya) average annual suspended sediment loads delivered to south Louisiana have decreased about 50 percent since the early 1950's.

c. The average annual volume of water transported by the Mississippi below the latitude of Red River Landing has decreased due to increased diversions to the Atchafalaya River since the middle 1800's.

d. Developments in the Atchafalaya Basin, following actions of the State of Louisiana to establish navigation on the Atchafalaya River in the middle 1800's, have significantly hastened the natural enlargement processes in the Atchafalaya Basin and Atchafalaya Bay.

e. Channel enlargements in the middle and lower reaches of the Atchafalaya Basin have been instrumental in channeling sediments to the Atchafalaya Bay, reducing the potential for overbank sedimentation in the Atchafalaya Basin above Morgan City, and causing acceleration of a significant marsh area in Atchafalaya Bay.

LITERATURE CITED

Elliott, D. C. The improvement of the Lower Mississippi River for flood control and navigation. U.S. Army Corps of Engineers, Mississippi River Commission, Vicksburg, Mississippi; 1932: 3 Vol.

Fisk, H.N. Geological investigation of the Atchafalaya Basin and the problem of the Mississippi River diversion. U.S. Army Corps of Engineers, Mississippi River Commission, Vicksburg, Mississippi; April 1952: 2 Vol.

Latimer, R.A.; Schweizer, C.W. The Atchafalaya River study. U.S. Army Corps of Engineers, Mississippi River Commission, Vicksburg, Mississippi; May 1951: 3 Vol.

Paper H, Sediment investigations on the Mississippi River and its tributaries prior to 1930. War Department, U.S. Army Corps of Engineers, Mississippi River Commission, St. Louis, Missouri; 1930.

Roberts, H.H.; Adams, R.D.; Cunningham, R.H.W., Evolution of sand-dominant subaerial phase, Atchafalaya Delta, Louisiana. Am. Assoc. of Petroleum Geologists Bull. 64:2; Feb. 1980.

Shen, H.W. River mechanics. 1971, 2 Vol.

ATCHAFALAYA DELTA: SUBAERIAL DEVELOPMENT ENVIRONMENTAL IMPLICATIONS AND RESOURCE POTENTIAL

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Baton Rouge, Louisiana

ABSTRACT

A major geologic event in the history of the Mississippi delta system is now in progress along the central Louisiana coast. Because of a distinct gradient advantage, the main distributary of the Mississippi River, the Atchafalaya River, is rapidly developing a subaerial delta in Atchafalaya Bay, 130 miles (200 km.) west of the modern bird-foot delta.

The subaerial growth of the new delta is being monitored with remote sensing techniques, land and hydrographic surveys and a sediment sampling program. Initial formation of new land in the Atchafalaya Delta has been found to occur sporadically with accretional periods coinciding with flood pulses of the river. Approximately 12.39 mi^2 (32 km^2) of new land had been formed by 1976 with additional accumulations following the 1979 flood.

A prototype data collection program is currently underway to provide data for a study of estuarine hydrodynamics and sediment transport in the bays and near offshore areas of the Atchafalaya-Vermilion estuarine complex. Accretional impact lines include subaerial deltaic sedimentation, subaqueous bay fill and mudflat-marsh building in a region formerly characterized by shoreline retreat. These impacts are presently producing negative effects on open water habitats, but the potential for improved marsh and aquatic nursery ground environments and expansion of human habitats in the vicinity of Morgan City far outweighs loss of open bay habitats. The Corps of Engineers is considering several project alternatives for mitigation of present impacts and management of future delta growth.

INTRODUCTION

A remarkable new geologic event in the 6,000 year history of the Mississippi delta complex is currently unfolding in Atchafalaya Bay, along the central Louisiana coast near Morgan City, Louisiana (Figure 1). Construction and abandonment of a major delta lobe of this system occurs on a time scale of about 1,000 years (Kolb and Van Lopik 1966). Since the present 800-year-old bird-foot Balize Delta has prograded far out onto the continental shelf, the Mississippi River has lost much of its efficiency for delivering water and sediment to the gulf.

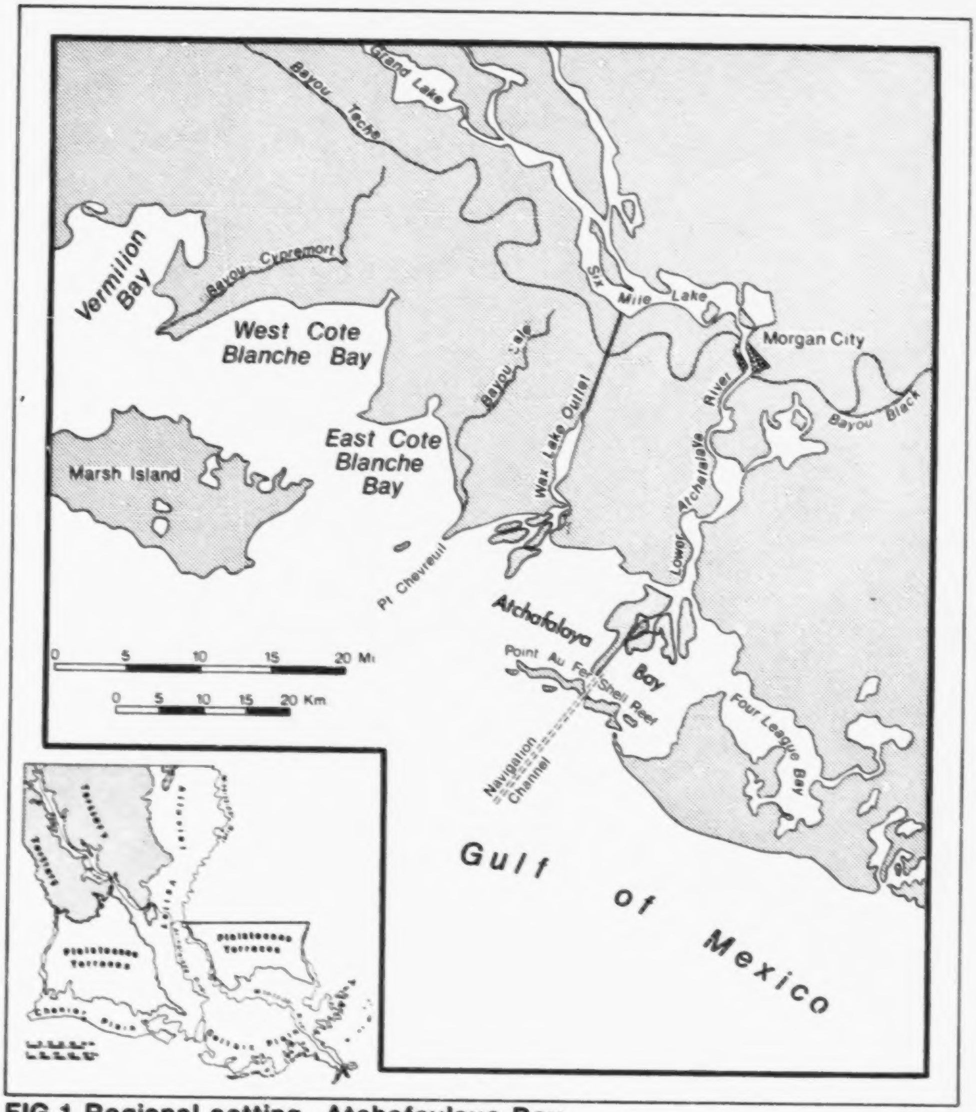
Grand Lake
Bayou Teche
Vermilion Bay
Bayou Cypremort
West Cote Blanche Bay
Six Mile Lake
Morgan City
Bayou Black
Bayou Sale
Wax Lake Outlet
Lower Atchafalaya River
East Cote Blanche Bay
Marsh Island
Pt Chevreuil
Atchafalaya Bay
Point Au Fer
Shell Reef
Four League Bay
Navigation Channel
Gulf of Mexico
0 5 10 15 20 Mi
0 5 10 15 20 Km
Tertiary
Tertiary
Pleistocene Terraces
Pleistocene Terraces
Chenier Plain
Deltaic Plain

FIG.1 Regional setting , Atchafaylaya Bay.

The Atchafalaya River, a venerable distributary of the Mississippi River, has a distinct gradient advantage because of its shorter route to the Gulf of Mexico. Aided by man's activity, the Atchafalaya has rapidly increased its proportion of the Mississippi's latitudinal flow to more than 30 percent during this century. The result has been the rapid development of a new delta 130 miles (200 km) west of the modern Balize Delta. The new Atchafalaya Delta is the fifth major event in the 6,000 year history of the delta system. The delta is building into an area where the effects of deltaic sedimentation have been absent for over 2,000 years (Frazier 1967). This region, traditionally characterized by shoreline retreat, is experiencing a reversal in the landloss trend and local shore line progradation.

This new episode of delta building started about 1950 (Shlemon 1975), but since the initial delta growth took place in the subaqueous (underwater) environments of Atchafalaya Bay, there was little awareness of this event during the first twenty years of development. In 1973 definite subaerial delta lobes and artifically created spoil islands began to appear at Atchafalaya Bay and by 1975, at the end of three consecutive high water years, in 1975, the emerging deltas had grown to encompass several square miles of the bay.

Associated environmental and engineering problems emerged quickly. Fisheries were disrupted as sediment-choked freshwater spread throughout adjacent bays and marshes. Channel shoaling impeded navigation on the heavily used waterways near Morgan City. Rapid changes in the flowline also created alarming flood control problems for Morgan City.

Scientists at Louisiana State University, Center for Wetland Resources became intensely interested in this delta-building episode because of the opportunity to study the estuarine hydrodynamic, geological and biological processes taking place. Through a cooperative effort with the Corps of Engineers, NOAA Sea Grant and Naval Oceanographic Programs, active monitoring of delta-building processes began in 1975.

The purpose of this paper is to address the development of the Atchafalaya Basin and the new delta, its impacts, and possible management alternatives to deal with these impacts.

ATCHAFALAYA BASIN DEVELOPMENT

The Atchafalaya River was a distributary of the Mississippi as far back as the 1500's (Fisk 1952). During the middle and late 1800's, flow from the Mississippi and Red Rivers into the Atchafalaya was increased by the removal of a log raft and dredging of a navigation channel. By the mid-1900's a natural channel had become so well established through the diversion that the volume of flow increased at an alarming rate. Total capture of Mississippi River flow seemed inevitable because of the Atchafalaya's shorter route to the Gulf of Mexico and its decided gradient advantage. Old River control structure, built in 1963, was designed to prevent this possibility by limiting the diversion into the Atchafalaya to approximately 30 percent of the flow of the Mississippi.

Because the lower course of the Atchafalaya River contained a network of lakes and swamp catchment basins, much of the sediment load carried by the increasing flow was deposited in these areas before it reached Atchafalaya Bay (Figure 2). Progressive sedimentation began to drastically reduce open water areas in the basin. Grand and Six Mile Lakes in the lower basin filled rapidly during the period from the 1930's through the 1960's. By 1975 only small remnants of open water remained.

It was not until the early 1950's that sedimentation at the coast began to initiate noticeable effects. This occurred only after the channel through the basin had developed well enough to convey silts and small amounts of sand to the bay. During the 1950's and 1960's silts and clays transported to the coast began to be deposited near the mouths of the outlets in the bay. By the early 1970's a thick platform of silty clay deposits covered not only Atchafalaya Bay, but adjacent offshore areas as well. As much as six feet of bay fill was deposited between 1952-1972 as the delta front advanced to the Point Au Fer shell reef (Shlemon 1975). Prior to 1972 very little sand-sized sediment was being deposited in Atchafalaya Bay.

The years 1973-75 were unprecedented flood years on the Atchafalaya River (Figure 3). River discharge doubled normal conditions during the peak flow periods. More importantly, both the volume and size distribution of sediments reaching Atchafalaya Bay changed dramatically (Table 1). An extraordinary increase in the amount of sand, scoured from the basin and transported to the bay, was noted during this period (Roberts et al. 1980).

ATCHAFALAYA DELTA DEVELOPMENT

CHANGES IN BATHYMETRY

Bathymetric changes in Atchafalaya Bay over the decade 1967-77 have been impressive. The 1967 map (Figure 4) shows silty distal bar deposits represented by the 4-foot contour were beginning development in the bay. By 1972 these deposits covered most of the bay.

Following the 1973-75 high water years, an extensive network of sandy distributary mouth bar deposits had emerged in both Wax Lake and lower Atchafalaya River lobes (Figure 5). Approximately 15 mi^2 of these deposits had become subaerially exposed (Rouse et al. 1978). A seaward extending, branching network of distributary channels had also developed.

The 1977 bathymetric chart emphasizes the tremendous volume of coarse-grained sandy material deposited during the 1967-77 decade. Figure 6 illustrates the areas of net accretion/erosion and their magnitudes in Atchafalaya Bay over the period (Roberts et al. 1980). Areas with accumulations of 7-8 feet are generally regions of dredge spoil accumulation. Small areas of bay scour are noted, due primarily to the increasingly restricted routes by which water can exit the bay.

As the initial subaerial phase of delta growth was monitored, using repetitive satellite imagery, it was noted that substantial increases in bar exposure became apparent only after major flood crests (Figure 7). Little growth was noted between these flood peaks. For example, 6 mi^2 (15.5 km^2) of bar exposure are shown on this image (A) following the

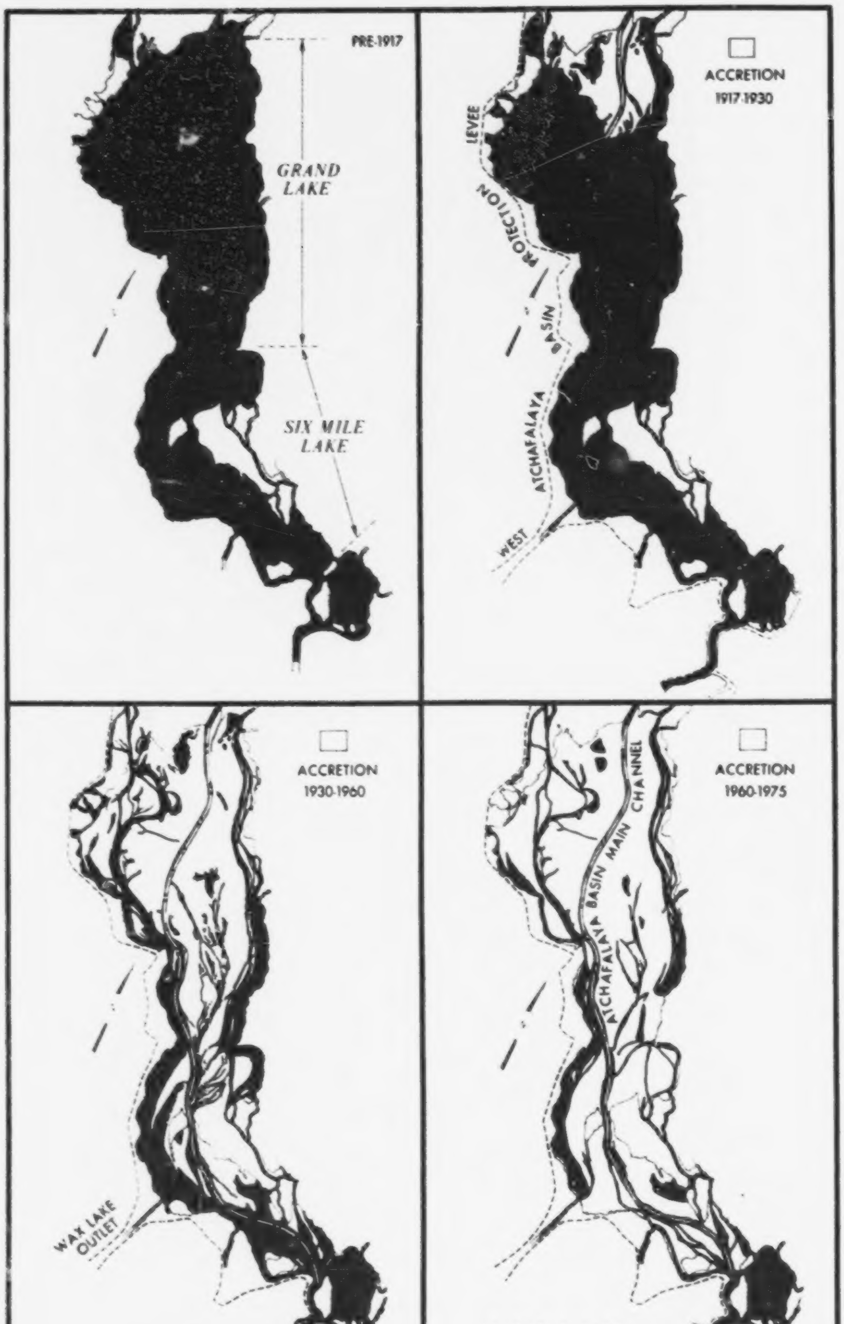
PRE-1917
GRAND LAKE
SIX MILE LAKE
ACCRETION 1917-1930
WEST ATCHAFALAYA BASIN PROTECTION LEVEE
ACCRETION 1930-1960
WAX LAKE OUTLET
LOWER ATCHAFALAYA RIVER
ACCRETION 1960-1975
ATCHAFALAYA BASIN MAIN CHANNEL
0 1 2 3 4 5 Mi
0 2 4 6 8 Km

FIG. 2 History of lacustrine delta fill, Grand and Six Mile Lakes. After Roberts et al. 1980.

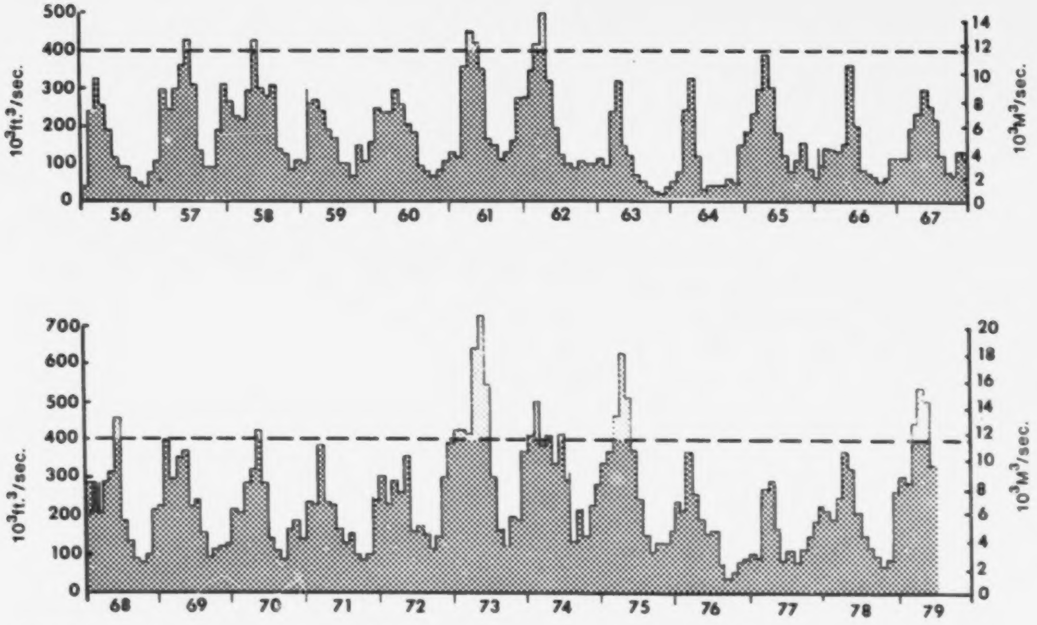

FIG. 3 Average monthly discharge of Atchafalaya River . USCOE data.

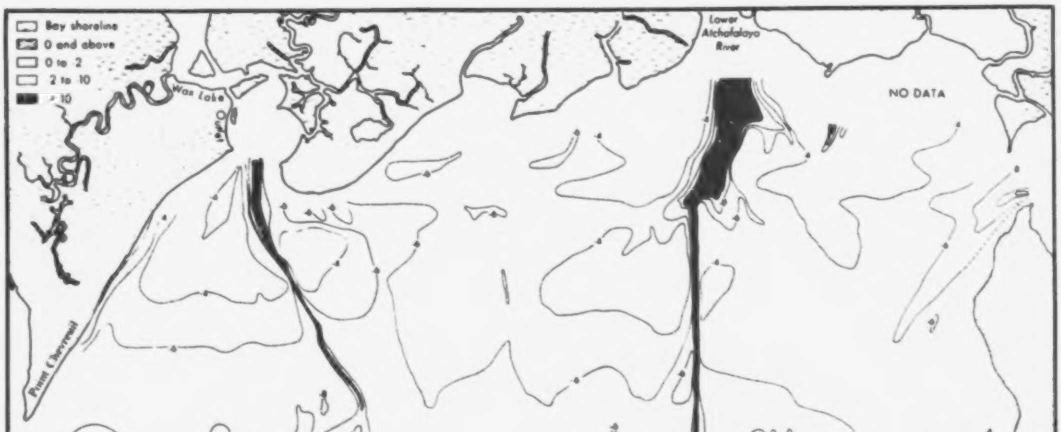
Bay shoreline
0 and above
0 to 2
2 to 10
> 10
Wax Lake
Outlet
Lower Atchafalaya River
NO DATA
Point Chevreuil
Point Au Fer
1967

FIG. 4 Bathymetric map, Atchafalaya Bay, 1967 (contours are in feet). USCOE data.

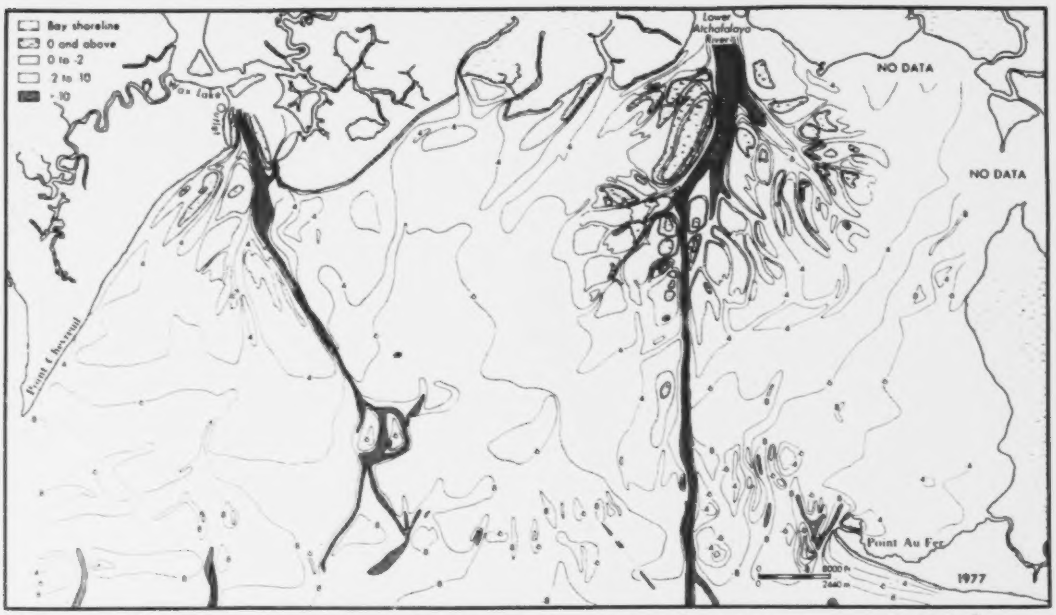
Bay shoreline
0 and above
0 to -2
2 to 10
10
Wax Lake Outlet
Lower Atchafalaya River
NO DATA
NO DATA
Point Chevreuil
Point Au Fer
8000 ft
2440 m
1977

FIG. 5 Bathymetric map, Atchafalaya Bay , 1977 (contours are in feet). USCOE data.

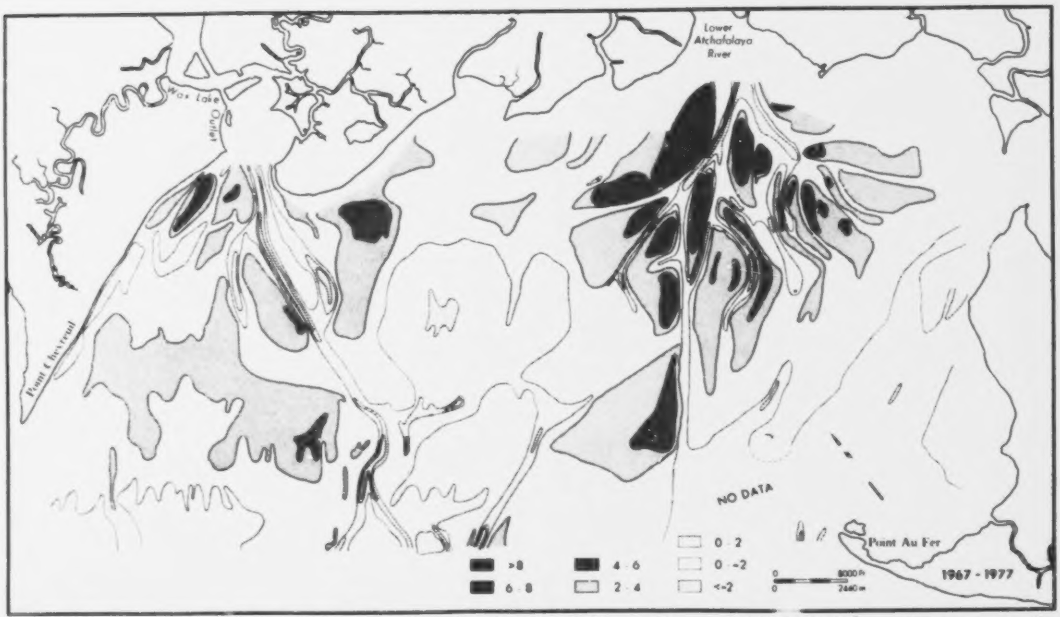
Lower Atchafalaya River
Wax Lake Outlet
Point Chevreuil
NO DATA
>8
6 8
4 6
2 4
0 2
0 -2
<-2
0
8000 ft
0
2440 m
Point Au Fer
1967 - 1977

FIG. 6 Net accretion and erosion in Atchafalaya Bay, 1967–77 (contours are in feet).After Roberts et al. 1980.

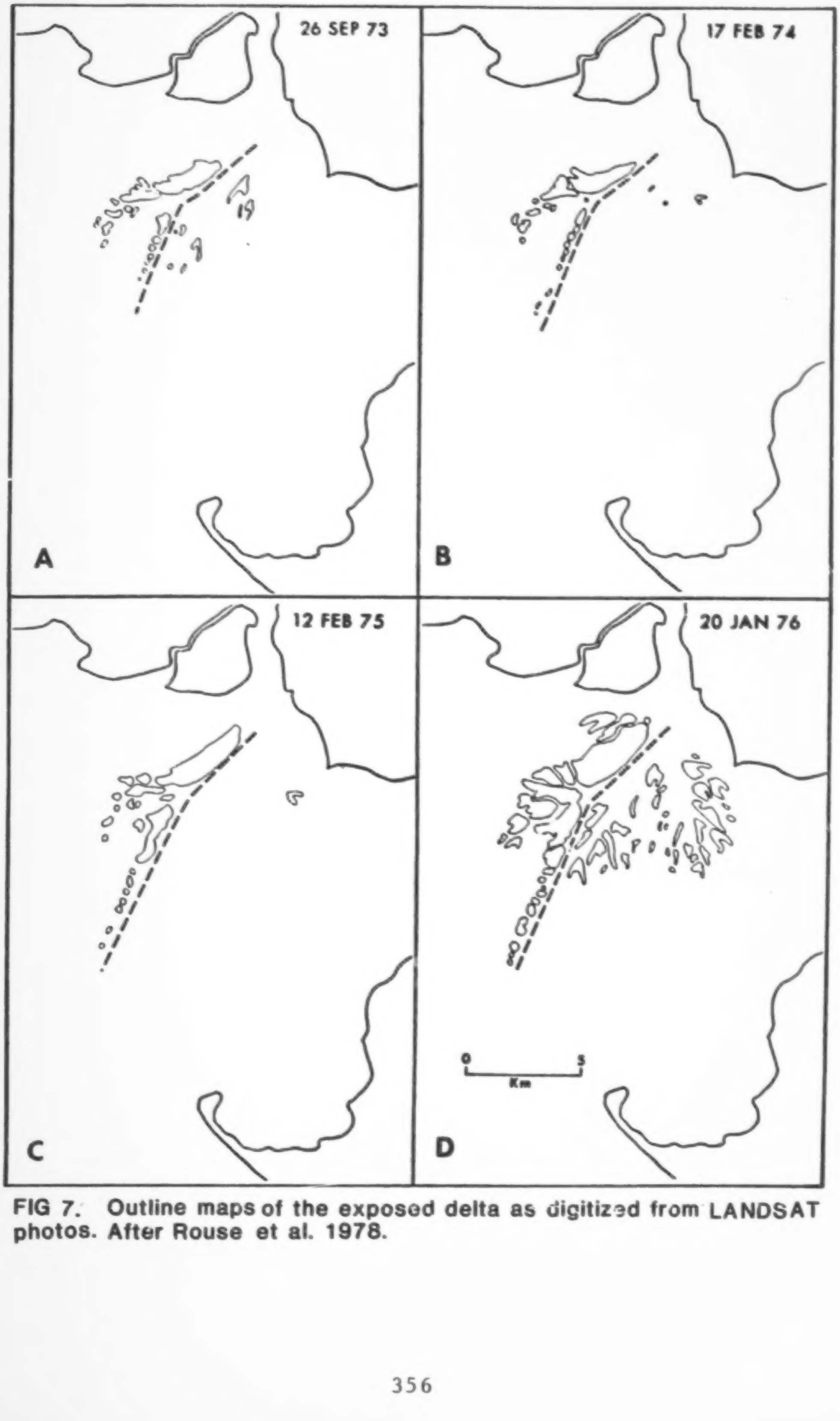
26 SEP 73
A
17 FEB 74
B
12 FEB 75
C
20 JAN 76
D
0
5
Km

FIG 7. Outline maps of the exposed delta as digitized from LANDSAT photos. After Rouse et al. 1978.

Table 1. Average Annual Suspended Load Budget, Atchafalaya River

	Input		Distribution of Input							
	Simmesport (Near Diversion Point	%	Basin Retention	%	Wax Lake Outlet	%	L. Atchafalaya River	%		Total (%)
1967-1971										
Sand	19,342	22	14,491	75	1,153	6	3,968	19	=	100 Sand
Silt/clay	67,905	78	10,179	15	15,590	23	42,136	62	=	100 Silt/clay
Total	87,247	100	24,670	29	16,743	19	45,834	52	=	100 Total
1973-1975										
Sand	37,506	25	3,668	10	5,748	15	28,090	75	=	100 Sand
Silt/clay	100,704	75	21,256	19	21,789	20	67,650	61	=	100 Silt/clay
Total	148,210	100	24,924	17	27,546	19	95,740	65	=	100 Total

NOTE: Computations from measured data and sediment rating curves, USACOE files. (1 ton = 0.907 metric tons) record flood of 1973. In 1974 little additional deposition, except for dredge material, was noted because of the absence of an extreme flood crest (B). In 1975 another major flood peak doubled the bar exposure to about 12 mi^2 (30 km^2) (D) (Rouse et al. 1978).

Another high water year was experienced in 1979 (Figure 3). Data for a new topographic survey are currently being compiled. Preliminary indications from recent aerial photography and island transects show marked aggradation or vertical buildup of existing islands, welding of several islands, and a reduction in the number of active distributaries. Only a small increase in the area of the delta was noted, indicating the possibility of a new phase of deltaic development--a subaqueous marine delta, forming just seaward of the Point Au Fer shell reef (Van Heerden 1980).

VEGETATION RESPONSE

The following table lists the acreages of vegetation colonizing the emergent islands:

	Natural Islands	Spoil Island Vegetation
1974	216	790
1975	380	796
1976	1,117	1,783
1977	no change	no change
1978	1,113	1,783

(1 acre = 0.0040 km^2)

Vegetation progradation showed a marked increase during a year following major flood, as was evident the year following the 1975 flood (Sasser personal communication). A slight decrease was noted during subsequent low water years due to a lack of sediment nourishment and erosional processes. Figure 8 illustrates vegetation progradation, covering approximately 4.5 mi^2 (11.7 km^2) of the delta as of the end of the 1978 growing season. Preliminary results from a 1980 vegetation inventory indicate another large increase in acreage resulting from the 1979 flood. All developing habitats in the delta have been documented as being freshwater habitats (Montz 1978).

REGIONAL IMPACTS OF DELTAIC PROCESSES

During the investigation of subaerial delta growth in Atchafalaya Bay it became apparent that the impact of the sediment-laden discharge from the Atchafalaya River extended far outside the confines of Atchafalaya Bay. In fact, estimates indicate that less than 50 percent of the fine-grained sediment transported to the bay is actually deposited there. Satellite imagery, available since 1972, tends to support this conclusion (Figure 9). Turbid flows were found to impact as little as 300 mi^2 during low discharge and as much as 1,200 mi^2 during flood periods.

To study these regional impacts, Landsat images collected between 1972-1977 were studied. Turbidity patterns which appear on the imagery were excellent indicators of the major components of estuarine circulation when correlated with a mathematical model tuned with wind and

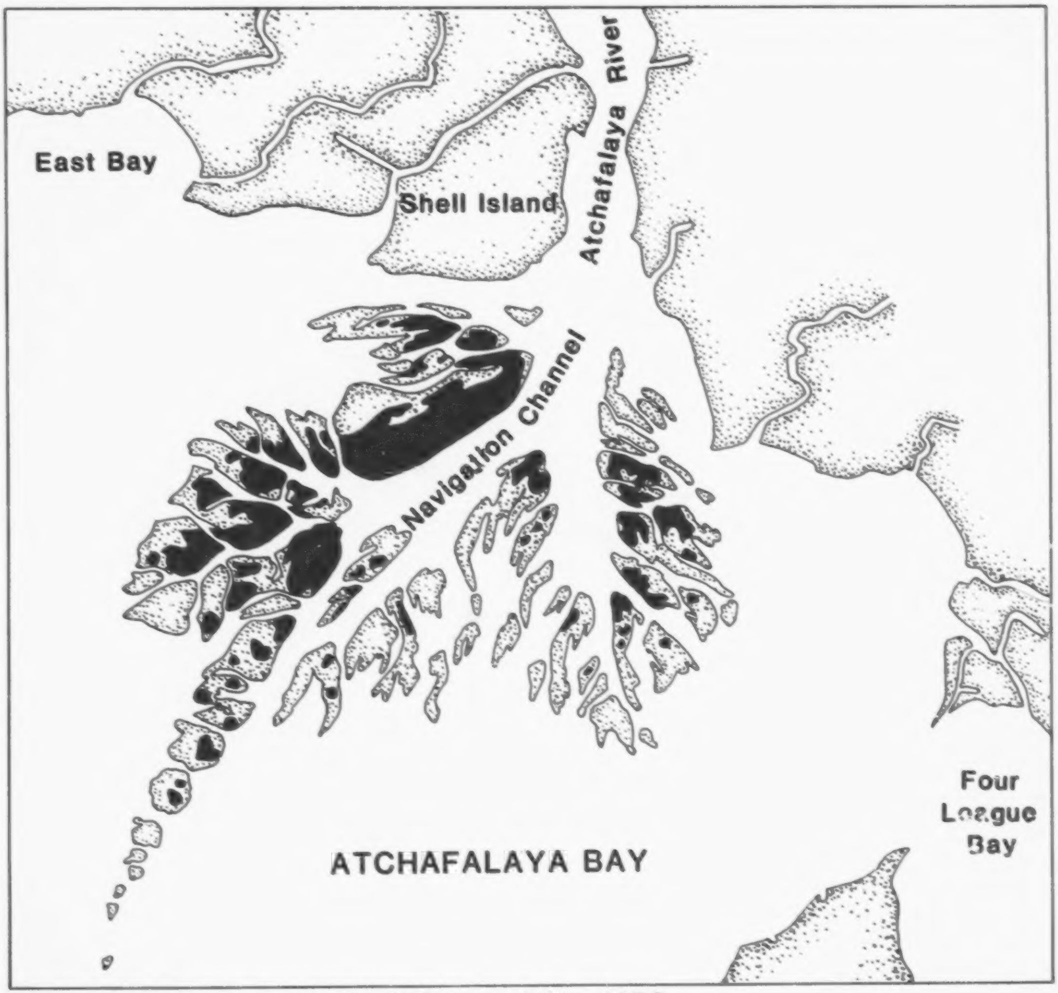
East Bay
Shell Island
Atchafalaya River
Navigation Channel
Four League Bay
ATCHAFALAYA BAY

FIG. 8 Vegetated areas. Atchafalaya delta ,1978.

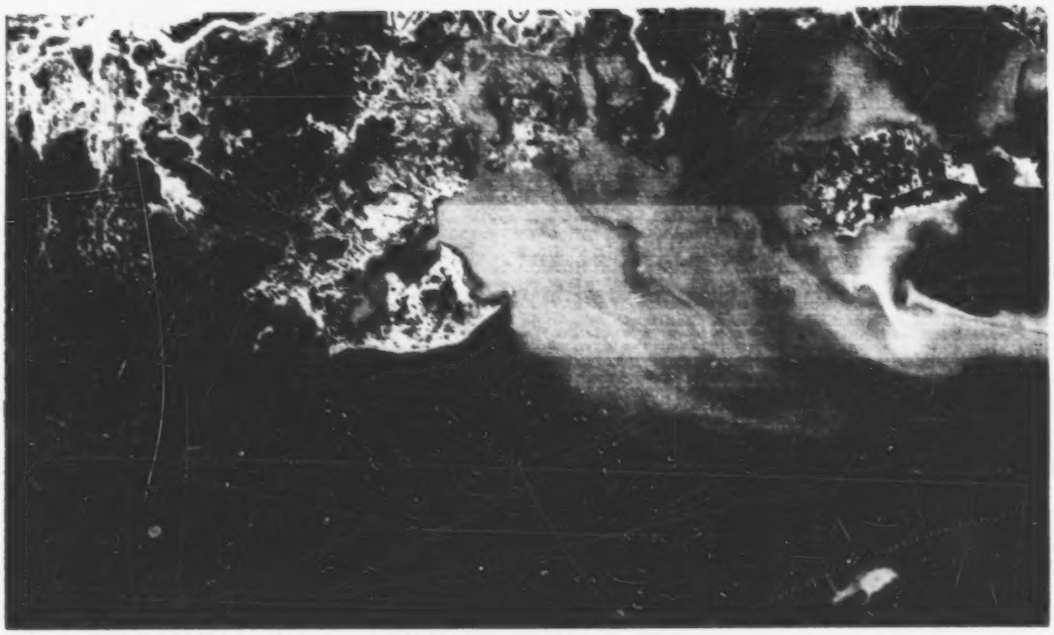

FIG. 9 LANDSAT Photograph, 30 Jan. , 1974.

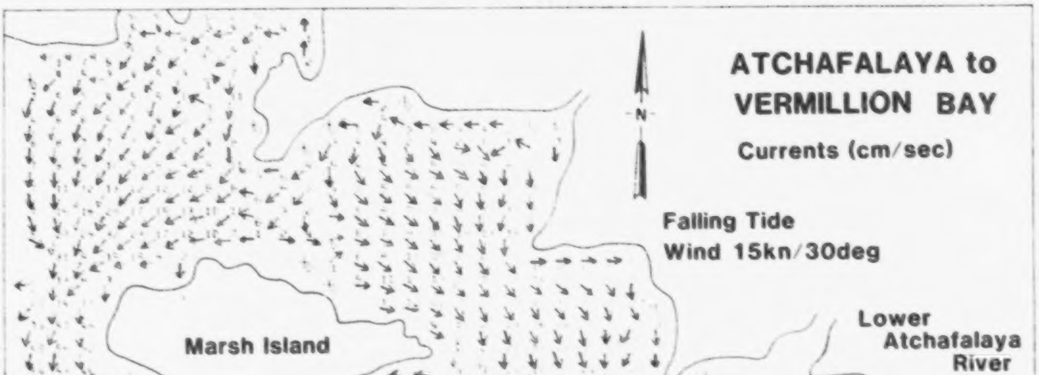
ATCHAFALAYA to VERMILLION BAY
Currents (cm/sec)
N
Falling Tide
Wind 15kn/30deg
Lower Atchafalaya River
Marsh Island

FIG. 10 Current vector plot: Hart 2-dimensional mathematical model.

tidal conditions occurring at the time of the satellite pass (Figure 10). Since the estuary is shallow and well mixed, patterns which appear at the surface on Landsat were considered to be representative of the water column in the bays. Offshore, the high sediment concentrations and sharp interface between the sediment plume and the more saline gulf water are thought to indicate strong mass density differences and a zone of flocculation.

The results of the remote sensing model study indicate a more pronounced impact to the west, due in part to the predominance of southeasterly winds in the spring during the peak discharge period. Complimenting tidal currents carry large volumes of sediment into the bays west of Atchafalaya Bay, as evidenced by a thick accumulation of sediments recently sampled in Vermilion Bay (Van Beek 1977). Mud flat accretion has been detected as far west as the Texas coast, carried by the prevailing westerly littoral drift.

An extensive prototype data-collection program, to provide data for a study of system hydrodynamics, sediment transport and delta growth trends, is currently underway in the estuary and near offshore areas. LSU-Sea Grant and Waterways Experiment Station are working cooperatively, as well as independently, on this extensive modeling effort.

PROSPECTS FOR THE REGION

Projections of delta growth made by the Corps of Engineers indicate that the bay will be essentially filled by subaerial delta deposits by the year 2000, extending well offshore by the year 2020 (USCOE 1974). LSU studies indicate a slightly more conservative estimate of bay filling in light of recent evidence of bay scour on the delta flanks and the sporadic flood-related nature of delta growth (Roberts et al. 1980).

Projections of delta growth are made somewhat easier since the Atchafalaya Delta is evolving in a similar manner as those described for subdeltas of the modern Mississippi River and other shallow water deltas (Figure 11). Presently the mass and aerial extent of the Atchafalaya Delta are comparable to that of the Mississippi River's Baptiste Collette sub-delta, which started its building phase in 1874. Deltas of the Colorado, Trinity and Guadalupe Rivers in Texas, which are growing into shallow bays behind barrier islands, are also somewhat analogous to the Atchafalaya setting.

However, several dilemmas are being posed by the growth of the Atchafalaya Delta which may bring about an alteration of natural delta growth patterns. Fisheries in the region have been severely impacted by excess fresh water and sediment loads. There has been a decline in shrimp and fish catches, and a near collapse of the oyster industry in the area (Van Beek 1977). The State of Louisiana discarded a sediment barrier plan, designed to ease these impacts in the bays to the west of Atchafalaya Bay, as ineffective.

There are equally pressing problems faced by flood control and navigation interests. Morgan City, for example, is severely threatened with flood problems created by rising flowlines resulting from delta growth. Navigation interests are plagued with shoaling problems and, at the same time, are requiring deeper draft

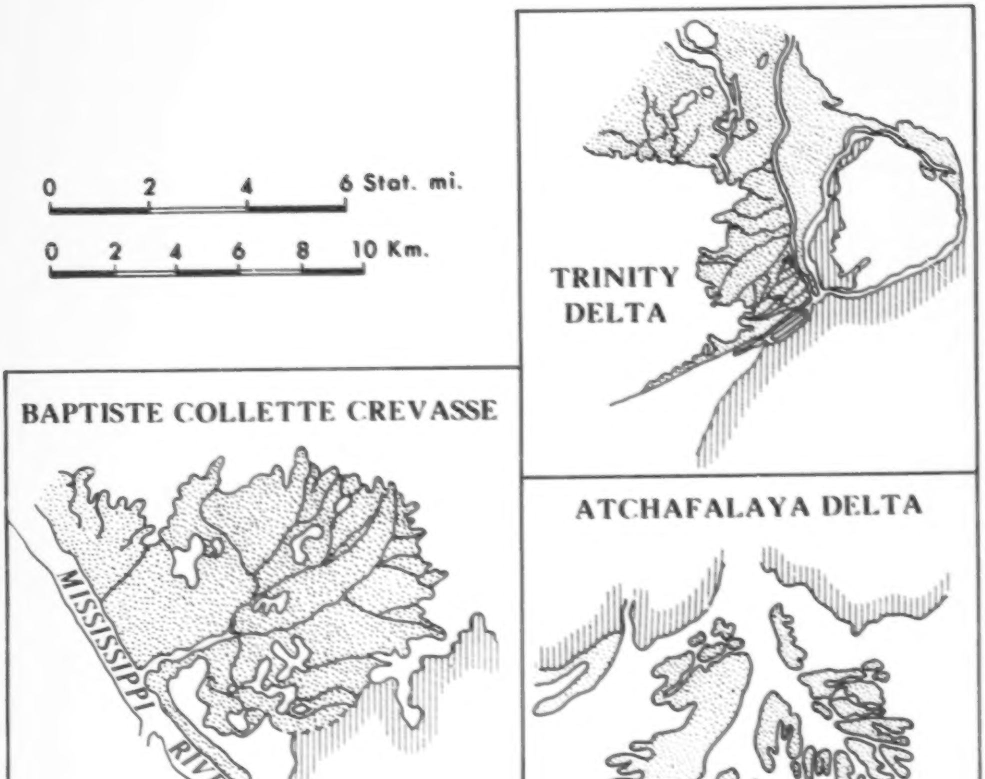
0 2 4 6 Stat. mi.
0 2 4 6 8 10 Km.
TRINITY DELTA
BAPTISTE COLLETTE CREVASSE
MISSISSIPPI RIVER
ATCHAFALAYA DELTA
GUADALUPE DELTA
COLORADO DELTA
MATAGORDA
PENINSULA

FIG. 11 Comparison of size and shape of Atchafalaya delta with crevasse-splay deposit of modern Mississippi River and other small modern deltas from coast of Texas.

navigation to support the booming oil industry. Levee and channel extensions are planned to alleviate these problems, but negative impacts associated with salinity intrusion and marsh deterioration are feared if the projects are built.

Other alternatives under consideration to aid these interests involve changes in distribution of flow between Wax Lake Outlet and the lower Atchafalaya River. Wax Lake Outlet is experiencing rapidly increasing flows at the expense of the lower Atchafalaya River because of its shorter route to the gulf. This is causing increased shoaling near Morgan City and loss of channel cross-sectional area for flood conveyance past Morgan City.

Among the proposals under consideration by the Corps of Engineers to alleviate this problem is a plan to construct a weir or overbank structure above Wax Lake Outlet. This structure would restrict the passage of normal flows while allowing high flows over the weir during flood events. The project would increase normal flows past Morgan City, encouraging natural channel scour, and hopefully result in an improved flood conveyance and improved navigation.

A citizens group from Morgan City has proposed a complete closure of the Lower Atchafalaya River above Morgan City, with 100 percent of the flow exiting at Wax Lake Outlet. While this plan would afford flood protection, the cost, coupled with negative environmental impacts, makes it infeasible.

None of these proposals will substantially alter long-term delta-building processes in the region; they will merely change the focal point of the impact. Regardless of the approach, there are urgent overall needs for Louisiana to capitalize on these deltaic processes.

Numerous studies have shown that a renewed cycle of delta growth is essential for the replacement of lost land and the maintenance of environmental productivity in the coastal zone as a whole. The regenerative effects of deltaic sedimentation are particularly necessary for the long-term health of Louisiana's seafood industry. The economic hardships for fishing and navigation interests in the Atchafalaya-Vermilion area can be eased, but not prevented. Perhaps the addition of new land will stimulate economic alternatives for this region, similar to the development between New Orleans and Venice, Louisiana.

Habitats and fishing grounds can shift in location and character in response to these deltaic processes. Unfortunately, people cannot. Economics dictate the maintenance of the status quo in a highly dynamic geologic situation. The greater the superimposition of people and their settlements in a rapidly changing area like the Atchafalaya-Vermilion region, the more complex the problems, and the more difficult the solutions.

SUMMARY AND CONCLUSIONS

The study of the subaerial growth and regional impacts of the Atchafalaya Delta have led to the following conclusions:

1. The subaerial phase of delta development started significantly after the flood of 1973, with abrupt increases in growth occurring following major flood events.

2. Vegetation progradation occurs most rapidly during the years following major floods, with little expansion noted during subsequent low water years due to erosional processes.

3. Sediment-laden discharge impacts surrounding bays, marshes and near offshore areas, with the most significant impacts occurring westward due to the combined impact of wind, tidal currents and littoral drift.

4. Delta growth may be substantially altered by man in order to mitigate the impacts of delta growth processes upon fisheries, navigation and flood control interests.

LITERATURE CITED

Fisk, H. N. Geological investigations of the Atchafalaya basin and the problem of the Mississippi River diversion: U.S. Army Corps of Engr., Miss. River Comm., Vicksburg, Miss. 1:145p; 1952.

Frazier, D.E. Recent deltaic deposits of the Mississippi River: their development and chronology. Gulf Coast Association Geological Society 1967; 287-311.

Kolb, C. R., Van Lopik, J. R. Depositional environments of the Mississippi River deltaic plain. Deltas in their geologic framework: 1966: 17-61. Available from Houston Geological Society.

Montz, G.N. Vegetational characteristics of the Atchafalaya River Delta. Proceedings of the Louisiana Academy of Sciences. 16:71-84; 1978.

Roberts, H. H., Adams, R. D., Cunningham, R. H. Evolution of sand-dominant subaerial phase, Atchafalaya Delta, Louisiana. Amer. Assoc. Petroleum Geologists Bull. 64:264-279; 1980.

Rouse, L. J. , Roberts, H. H., Cunningham, R. H. W. Satellite observations and subaerial growth of the Atchafalaya delta, Louisiana. Geology 6: 405-408; 1978.

Sasser, C. E. LSU-Sea Grant sponsored research, unpublished.

Shlemon, R. J. Subaqueous delta formation - Atchafalaya Bay, Louisiana. Deltas: 1975: 209-221; Available from Houston Geological Society .

U.S. Army Corps of Engineers (USCOE). Preliminary draft environmental impact statement, Atchafalaya Basin floodway. New Orleans District; 1974.

Van Beek, J. L. A jetty from Pt. Chevreuil: an evaluation of a proposal to reduce sedimentation in the Cote Blanche and Vermilion Bays. Coastal Environments Inc. for Louisiana State Planning Office; 1977: 59p.

Van Heerden, I. H. Sedimentary responses during flood and nonflood conditions, Atchafalaya delta, Louisiana. Baton Rouge: Louisiana State University; 1980. 150 p. Master's Thesis.

DISCUSSION

Question: You stated that your measurements show that about 50 percent of the sediment delivered to Atchafalaya Bay vicinity is being retained in delta building and related processes, and that another 50 percent is escaping. Is that basically correct?

Answer: The only thing we have to base that estimate on are some hydro surveys done in the bay and some cross-sectional sediment range measurements taken inside the basin from which we computed sediment budgets for the Atchafalaya Basin. What leaves the system was determined by looking at sequential hydrographic surveys. Looking at one in 1967, one in 1972, and one in 1977, we have tried to quantify the amount of deposition in the bay. And then we just simply subtract the amount of deposition from what was coming into the system and, from that, we determined that less than 50 percent of the material is being retained in the bay. But that's not exactly the whole story because the type of material that is being retained in the bay is the coarse-grained material or the sandy material, whereas the fine silts and the clay particles as seen on the landsat imagery, are easily escaping the bay with tidal processes. It's a complex problem.

Question: I have a second part to my question. My name is Sherwood Gagliano. Is the escape of this other 50 percent or less due largely to the maintenance of the navigation channel through the Achafalaya, and, if so, has the sediment transport in that channel been measured?

Answer: We're currently in a cooperative program with USGS measuring some of the major distributaries in the delta. However, it's almost impossible, as your group has found, to measure out around Eugene Island at the break in the reef, where the navigational channel cuts through, to determine just how much is escaping by that route. But I understand in talking to Johannas that your measurements indicate that perhaps as much as 20 percent is escaping at least below the subaerial portion of the delta. Whether or not it's going into the bay or the reef, no one knows. There is some indication from our studies that there is a good possibility of a marine delta forming seaward of the shell reef. We have some side scan sonar data and sediment data and there's been some sand sampled out there. It could be that the dredging of the navigation channel and the confinement of flow is carrying some of the sediment out beyond the reef. But you know, this is all kind of speculation right now. We haven't really confirmed that. We're working on that problem right now.

Speaker: John Weber "Planning Problems Associated with Freshwater Introduction into Louisiana Coastal Areas"

Question: (Dan Taylor, Fish and Wildlife Service). Have your studies progressed far enough to determine what you will tie the fish and wildlife benefits to. That is, what physical parameters, like the movement of isohalines, or reduction in marsh deterioration, and, if so, what do you plan to tie those benefits to?

Answer: I'd like to pass that question on to the next speaker. He's more familiar--are you talking about the Mississippi-Louisiana Estuarine Study, or both of them?

FRESHWATER INTRODUCTION INTO LOUISIANA COASTAL AREAS

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Corps of Engineers, New Orleans, Louisiana

ABSTRACT

The conservation and enhancement of fish and wildlife resources through the control of salinities in portions of the estuarine area of Louisiana are the purposes of one authorized project and two ongoing studies in the U.S. Army Engineering District, New Orleans. The primary measure identified for controlling salinities is to divert water from the Mississippi River near the delta to adjacent estuarine areas. Planning and implementing this type of project presents a challenge from both technical and institutional standpoints. Technically, the state-of-the-art for quantifying benefits and impacts must rely on expert judgment and assumptions. From the institutional aspect, freshwater diversion is supported by many Federal, State, and local agencies and organizations. However, obtaining local cooperation and support for specific diversion sites may be the most difficult problem to solve because the local areas where diversion facilities would be located are not necessarily the areas receiving significant benefits from diversion. In some areas, benefits may not outweigh adverse impacts involved with constructing and operating diversion facilities. For the most part, benefits would be widespread and would accrue to interests not directly participating in the project.

AREA DESCRIPTION AND BACKGROUND INFORMATION

The State of Louisiana contains one of the Nation's most productive estuarine areas. The area consists of 363 miles of shoreline directly fronting waters of the open Gulf of Mexico (Becker 1972) and is predominantly composed of 4.2 million acres of estuarine marsh lying at or near National Geodetic Vertical Datum (NGVD) (U.S. Army Corps of Engineers 1970). Pocked with numerous shallow lakes and bays and interlaced with a complex network of channels and canals, both natural and manmade, this mixing zone represents a resource of great value to the State and Nation. It is estimated that there are nearly 30,200 total miles of shoreline in the area, including the tidal shorelines of bayous, rivers, marsh lakes, islands, and canals (Becker 1972). The salinities of the waters in the lakes, bays, and channels vary from near zero to over 28 parts per thousand, depending upon location and numerous climatological, meteorological, and hydrological factors.

A unique feature of the estuarine area is its interrelationship with the Nation's largest river, the Mississippi. The average flow of the Mississippi River into the area is about 450,000 cubic feet per second (U.S. Army Corps of Engineers 1970). Below Old River, the Mississippi transports some 300,000,000 tons of sediment in an average year (U.S. Army Corps of Engineers 1970). Most of the present estuarine-marsh complex owes its existence to the delta-building process of the Mississippi River. Historically, the Mississippi River annually overflowed the vast marshlands and estuaries, depositing sediments throughout the flood plain and also in the shallow waters of the Gulf of Mexico, over the continental shelf. The sedimentation from these yearly floods generally exceeded in total effect the attritional processes of erosion, compaction, and subsidence, so that the shoreline advanced seaward (U.S. Army Corps of Engineers 1970).

Investigations have disclosed that continuing change is taking place in nearly all of the important physical and chemical parameters from which the area derives its unique character. Further, it has become apparent that these changes relate, in the long-term sense, primarily to the alteration of the overflow regimen of the Mississippi River. In the past 250 years, man has increasingly restricted the river overflow into the estuarine zone in Louisiana through the construction of works to control devastating floods and to provide for dependable navigation. Deprived of the overflow, with its nourishing sediments, the area is yielding to the sea through subsidence and erosion. Another important source of change in Louisiana's estuarine area is the development of the area for various economic pursuits, particularly those associated with the fisheries and petroleum industries. The construction of new waterways to service these industries has had a profound effect on salinities and flow patterns in the area (U.S. Army Corps of Engineers 1970).

ESTUARINE AREA STUDIES

A number of agencies at the Federal, State, and local level have recognized the changing conditions of the Louisiana estuarine environment. As a result, Congress has directed the U.S. Army Corps of Engineers to undertake certain investigations to determine the feasibility of providing water resource improvements in the interest of conservation and enhancement of fish and wildlife resources. The U.S. Army Engineer District, New Orleans, has conducted several investigations involving diversion of freshwater from the Mississippi River to portions of the estuarine area. The earliest study, conducted in the late 1950's, resulted in the congressional authorization of the Mississippi Delta Region Salinity Control project. The project, which is depicted in Figure 1, was authorized by the Flood Control Act of 1965 as part of the Comprehensive Plan for Modification of Flood Control and Improvement of the Lower Mississippi River (U.S. Army Corps of Engineers 1979). It consists of four gated-water or salinity-control structures on the banks of the Mississippi River with connecting levees and channels that will introduce fresh water from the Mississippi River to the bays and marshes of the Mississippi Delta. Salinity-control structures would be located on the east bank of the river at Bohemia and Scarsdale and on the west bank at Myrtle Grove and Homeplace. The objective of the project is to increase wetlands productivity by the establishment of an ecological regimen favorable to the production of oysters, shrimp, fish, furbearing animals, and migratory waterfowl. The current estimated cost of the project is $30,000,000, of which $22,500,000

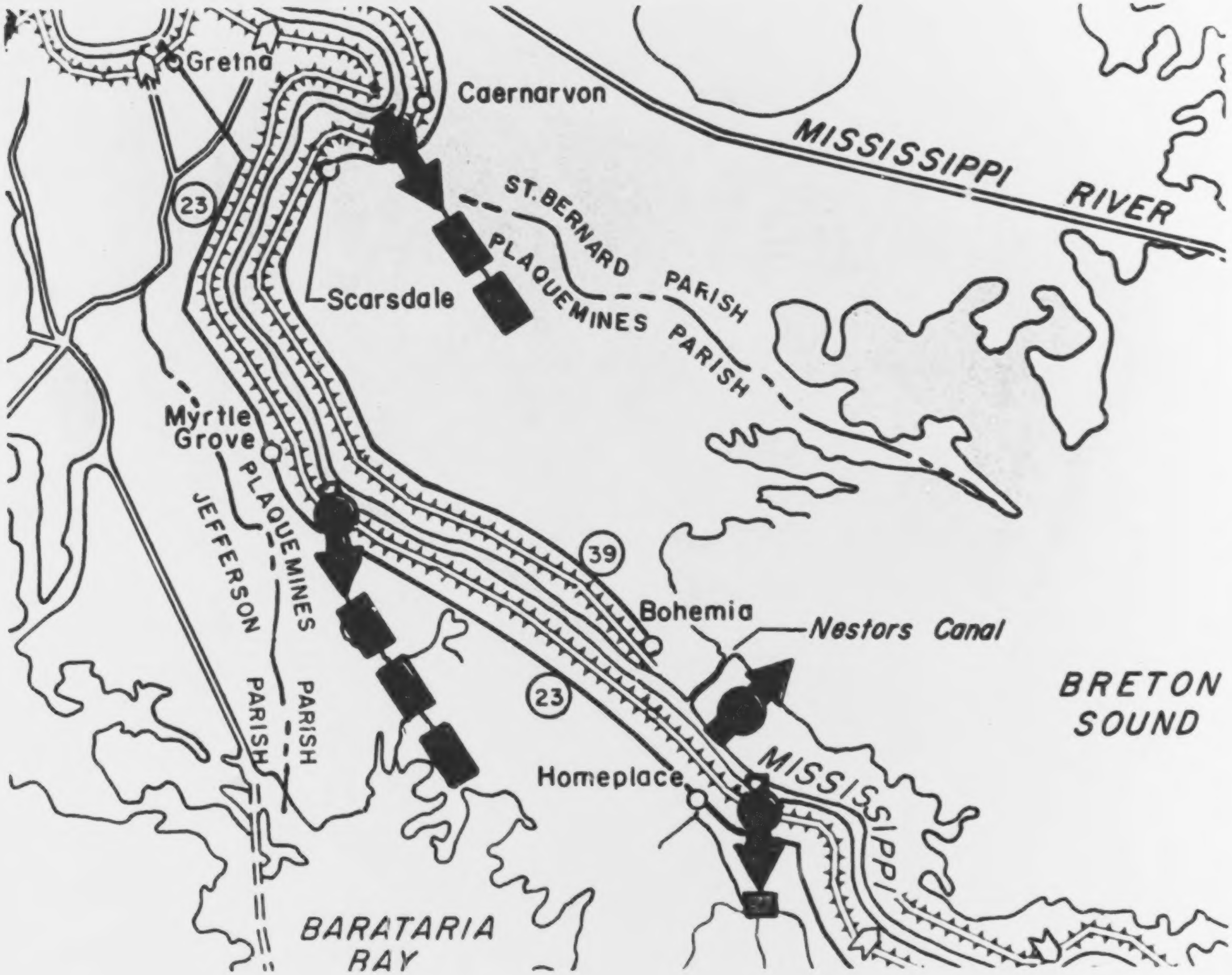
Gretna
Caernarvon
MISSISSIPPI RIVER
23
Scarsdale
ST. BERNARD PARISH
PLAQUEMINES PARISH
Myrtle Grove
JEFFERSON PARISH
PLAQUEMINES PARISH
39
Bohemia
Nestors Canal
BRETON SOUND
23
Homeplace
MISSISSIPPI
BARATARIA BAY

Figure 1. Mississippi Delta Region Salinity Control Project.

is Federal and $7,500,000 is non-federal (U.S. Army Corps of Engineers 1979).

In addition to the Mississippi Delta Region project, the New Orleans District is conducting two ongoing studies which involve providing fresh water to coastal Louisiana in the interest of improving the wildlife and fisheries resources. These studies are entitled "Louisiana Coastal Area" and "Mississippi and Louisiana Estuarine Areas."

The purpose of the Louisiana Coastal Area study is to review reports on coastal area projects to determine the advisability of improvements, or modifications to existing improvements, for hurricane protection, prevention of saltwater intrusion, preservation of fish and wildlife, prevention of erosion, and related water resource purposes. The study area is shown in Figure 2. In support of the overall study effort, a number of broad-scope investigations were conducted to provide basic information concerning the vegetation, water and soil characteristics of the coastal area, the hydrological and geological characteristics and trends, and management and structural approaches to solving problems in the coastal area. A fish and wildlife investigation conducted by the district with participation of an interagency group identified tentative optimum salinity gradients for the fish and wildlife resources, the quantity and cyclic amount of supplemental fresh water required to obtain the desirable salinity gradients, and investigated potential diversion sites. The study concluded that freshwater diversion is feasible and that further studies should be undertaken to determine the economics and overall justification of the diversion measures. Preliminary evaluations are underway for 17 potential diversion sites along the Mississippi Rvier to the Barataria Basin and Breton Sound.

The Mississippi and Louisiana Estuarine Areas study will comprise a review of the reports on the Mississippi River and tributaries flood control project and other pertinent reports prepared by the Corps, with a view toward determining the advisability of providing freshwater into Lakes Maurepas, Ponchartrain, and Borgne, and Mississippi Sound to improve wildlife and fisheries resources. Figure 3 shows the study area. Currently underway for this study are reconnaissance investigations of 12 sites on the east bank of the Mississippi River.

TECHNICAL ASPECTS

Actual experience with diversions for the purpose of conservation and enhancement of fish and wildlife resources has been very limited. On the east bank of the Mississippi River, local interests have constructed and are operating three small diversion projects. However, the quantity of river flow diverted by these projects is small and only affects several hundred acres of the estuarine-marsh area in the immediate vicinity of the discharge points. Very large diversions of water to the estuaries to the east of the river have occurred, but these diversions were for the purpose of flood control, as opposed to fish and wildlife enhancement, and information on them has only been documented to a limited extent. The diversions include the 1927 artificial crevasses of the Mississippi River levee at

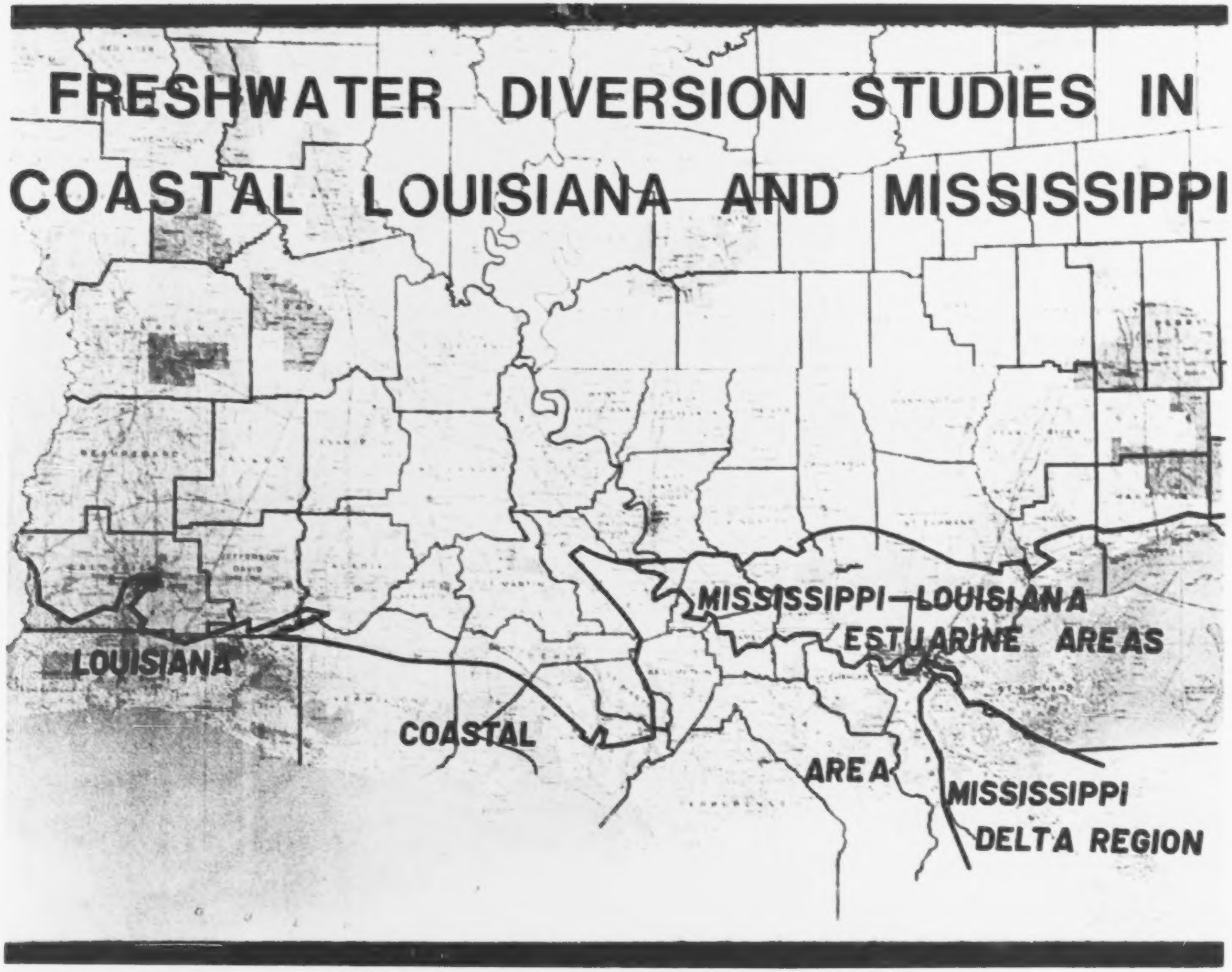
FRESHWATER DIVERSION STUDIES IN
COASTAL LOUISIANA AND MISSISSIPPI
LOUISIANA
COASTAL
AREA
MISSISSIPPI—LOUISIANA
ESTUARINE AREAS
MISSISSIPPI
DELTA REGION

Figure 2. Freshwater Diversion Studies in Coastal Louisiana and Mississippi.

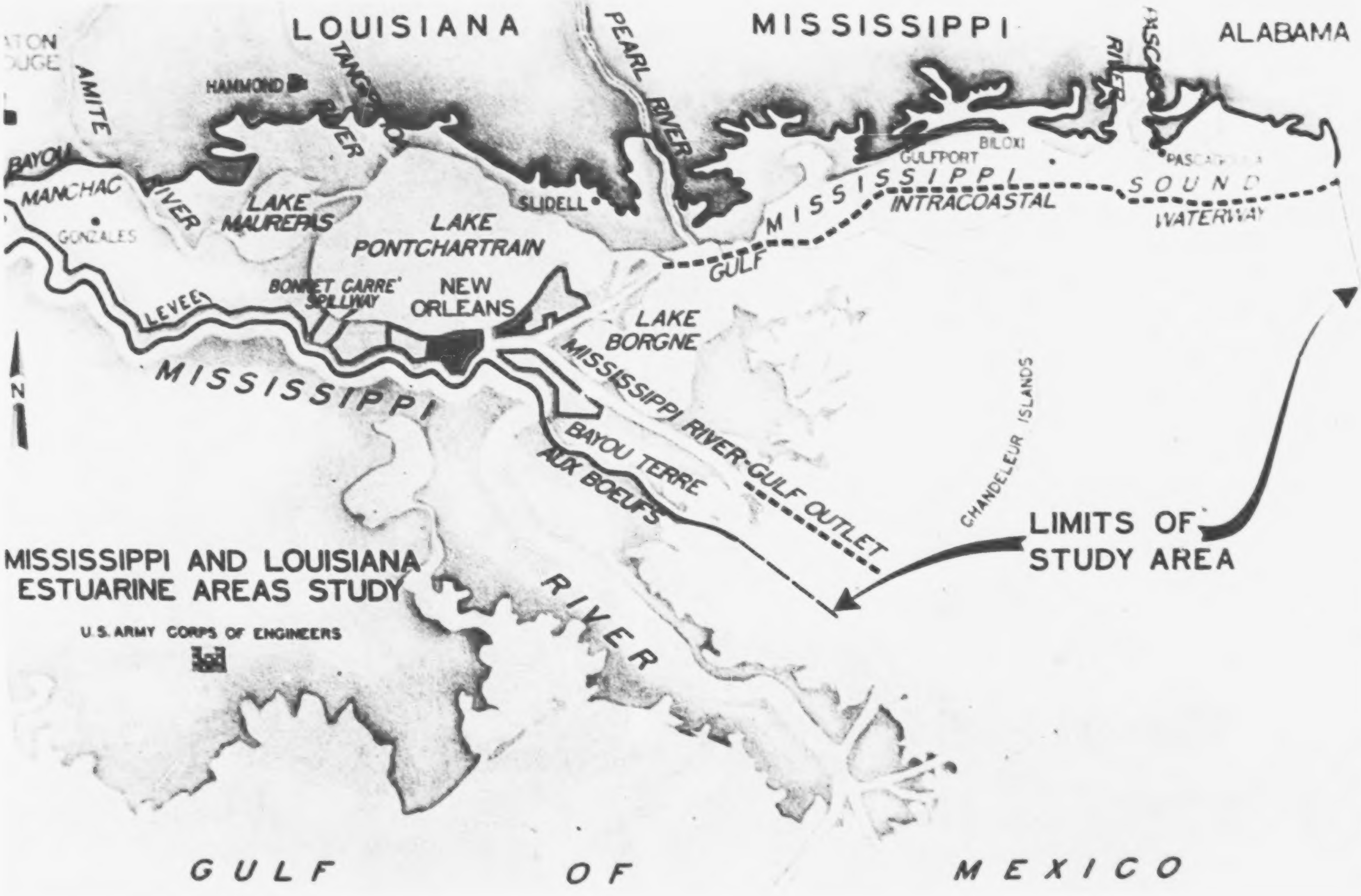
LOUISIANA
MISSISSIPPI
ALABAMA
HAMMOND
AMITE
TANGIPAHOA RIVER
PEARL RIVER
PASCAGOULA RIVER
BAYOU MANCHAC
AMITE RIVER
GONZALES
LAKE MAUREPAS
LAKE PONTCHARTRAIN
SLIDELL
GULFPORT
BILOXI
PASCAGOULA
MISSISSIPPI SOUND
GULF INTRACOASTAL WATERWAY
LEVEE
BONNET CARRE' SPILLWAY
NEW ORLEANS
LAKE BORGNE
MISSISSIPPI RIVER-GULF OUTLET
BAYOU TERRE AUX BOEUFS
CHANDELEUR ISLANDS
LIMITS OF STUDY AREA
MISSISSIPPI RIVER
N
MISSISSIPPI AND LOUISIANA ESTUARINE AREAS STUDY
U.S. ARMY CORPS OF ENGINEERS
GULF OF MEXICO

Figure 3. Mississippi and Louisiana Estuarine Study Area.

Poydras, Louisiana, and openings of the Bonnet Carre Spillway in 1950, 1973, 1975, and 1979. The spillway is a feature of the Mississippi River and tributaries project, located about 33 miles above New Orleans. It is designed to introduce floodwaters from the Mississippi River to Lake Ponchartrain to prevent overtopping of levees at and below New Orleans. Data on these flood control diversions indicate that after a short-term adverse impact, dramatic increases in fish and wildlife populations have been experienced for the next several years. Considering the limited information on actual experiences, the technical studies will necessarily be mostly theoretical.

Of the technical studies that must be conducted, the ecological studies play a crucial role and form a base for the engineering and economic studies. The ecological studies must quantify the physical and chemical changes desired in the environment to produce optimal conditions for fish and wildlife resources. However, because of the presently imprecise nature of the science, these analyses are difficult to perform. Our current knowledge of relationships between changes in the physical and chemical parameters and biological communities are based largely on inductive reasoning and expert judgment.

Because the optimal conditions to be achieved by the diversions cannot be precisely defined, a logical approach to the study is to stage development of the project. Under this approach, a diversion plan would be developed based on current ecological studies and other technical studies that are dependent on the ecological studies, all of which would be performed at the same level of detail. Studies for site evaluation, design, and cost estimates would be performed at a full level of detail. Prior to construction of the entire project, a pilot element would be constructed to provide sufficient data to reevaluate and modify additional elements of the plan, as necessary. Such an approach would also facilitate resolution of institutional arrangements for specific sites and permit construction at the earliest practicable time.

INSTITUTIONAL CONCERNS

Developing institutional arrangements to divert Mississippi River flow to adjacent estuaries is a difficult task. Both political and social institutions play an essential role in the planning process and can be critical determinants of the implementability of a plan. The capability and willingness of existing institutions to meet project requirements in monetary, and nonmonetary terms is a necessary ingredient for eventual realization of a diversion plan. The institutions considered critical include, among others, State, parish (same as county), and municipal governments and agencies, tax structures, and general local and regional attitudes. Potential diversion sites along the Mississippi River are all located in the State of Louisiana in 10 parishes which have political jurisdiction over the lands adjacent to the river. In addition, numerous cities, towns, and communities, including the city of New Orleans, are located on the banks of the river in the area.

A major complication with freshwater diversion is that a project of the magnitude being considered would have serious adverse as well as beneficial effects. The beneficial effects would be widespread in relation to the adverse effects, which would be concentrated at and near the diversion sites. The adverse effects can be separated into two distinct categories: those that would occur in the developed areas adjacent to the river, and those that would occur in the estuarine area at and in the vicinity of the freshwater introduction. The latter type would be an adverse impact on the environment and fish and wildlife resources.

The general configuration of the lower Mississippi River and the development of the area play a major role in the problem. The natural alluvial levees and ridges located beteeen the Mississippi River and uplands adjacent become highly developed as urban, industrial, and prime agricultural lands. These developed lands have been protected from Mississippi River floods and, in most cases, from tidal flooding from the direction of the estuaries. Any diverted river flow must be routed through these developed lands, which would cause problems in these areas. Each diversion site would require at least structures in the Mississippi River levee to insure continued flood protection, and at many possible sites, additional structures would be required in levees bordering the estuaries. For diversions of the magnitude considered essential to affect major portions of the estuaries, channels are required to convey the flow. These channels would require lands, relocations of residential and commercial structures, and modifications to intercepted drainage systems, roads, streets, railroad tracks, pipelines, and utilities.

The detrimental effects on the estuaries could include localized short-term impacts in the vicinity of the freshwater introduction and long-term impacts that would encompass a much larger area. Anticipated adverse impacts consist of the following: high levels of coliform bacteria, heavy metals, pesticides, phenols, and PCBs; too fresh an area for oysters and other sessile organisms to survive; temperature differences (river water is cooler); and increased turbidity. The magnitude and extent of the areas adversely affected would vary depending on the location of diversions. However, the percentage of the area adversely affected would probably be small compared to the area benefited. Downriver sites are the most effective, but the estuarine areas that would be adversely affected are among the most productive and are heavily fished.

Another factor that will influence local institutions is the contribution that fish and wildlife resources make to the local economies. Generally, the importance of fish and wildlife to the local economies increases progressively from upriver to downriver. Therefore, the situation occurs that where fish and wildlife are not economically important, the adverse impacts and commitments necessary are not offset by the benefits to the local area. At downriver sites, fish and wildlife may be important from an economic viewpoint, but because the detrimental effects in both the developed and estuarine areas are not offset by the benefits in the local area, local interests do not usually find such a plan acceptable. This latter situation is one of the reasons why the authorized Mississippi Delta Region has not been implemented.

There is no doubt that the benefits from a diversion project would be regional in nature and accrue to local and regional interests that are not directly participating in the project. For this reason, the concept of river water diversion is broadly supported; however, the institutional difficulties at the local level have not yet been resolved. The most commonly suggested approach to resolution of the problem is for all interests that will benefit from the project to organize and provide some sort of recompense to those that would be adversely affected. This sort of solution could be accomplished in a number of ways. Currently, alternatives for minimizing the adverse impacts are being fully explored.

SUMMARY

Many problems and difficulties must be overcome to achieve effectual salinity alterations in the Louisiana coastal zone. Because of the difficulties in projecting finite impacts and benefits, a pilot project should be constructed which would afford opportunity to collect and evaluate extensive biological and water quality data. The analysis of these data would provide a means to modify additional elements of the overall plan. An aggressive approach must be implemented to educate local interests of the merits of freshwater diversion and overcome institutional problems.

LITERATURE CITED

Becker, R. E. Measurement of coastal Louisiana's shoreline. Hydrologic and Geologic Studies of Coastal Louisiana. Report No. 15. Baton Rouge, LA: Coastal Resources Unit, Center for Wetland Resources, Louisiana State University; 1972.

U.S. Army Corps of Engineers, New Orleans District. Report on Mississippi River flow requirements for estuarine use in coastal Louisiana. Fish and Wildlife Study of the Louisiana Coast and the Atchafalaya Basin; 1970; 28p.

U.S. Army Corps of Engineers, New Orleans District. Plan of Survey, Louisiana Coastal Area; 1975; 58p.

U.S. Army Corps of Engineers, Lower Mississippi Valley Division. Water Resources Development by the U.S. Army Corps of Engineers in Louisiana; 1979; 205p.

DISCUSSION

Question: Dan Tabberer Fish and Wildlife Service. Have your studies progressed far enough to determine what you will tie the fish and wildlife benefits to, that is, what physical parameters, like movement of isohalines or reduction in marsh deterioration, and, if so, what do you plan to tie those benefits to?

Answer: I'd like to pass that question on to the next speaker, he's more familiar with them. Are you talking about the Mississippi-Louisiana Estaurine Study, or both of them?

Question: Either one.

Answer: I guess a fair answer to your question, Dan, is that I don't know if we've progressed to that point, but I don't see where it makes that much difference which parameters we tie them to as long as we can document the benefits associated with that diversion. And, as I mentioned to you earlier this morning, we can recommend to Congress a program that has a B.C. (benefit/cost) ratio of less than one if it is an environmental enhancement project. The district engineer views freshwater diversion in that manner and he would have no problem at all recommending to higher authority that the project be authorized even though we are having problems coming up with monetary values for benefits.

Question: Just what is your anticipated schedule for implementation of the first structure?

Answer: That is somewhat in the state of flux, because the Louisiana Coastal area study is a long-term study so what we have to do with that one is to get authorization to go with an interim report to address just freshwater diversion instead of erosion prevention and hurricane protection and other things we're supposed to study. The request to do that is now in Washington and we're waiting for approval. And as far as the Mississippi-Louisiana estuarine study, we're attempting to accelerate that schedule and combine the state two and three phases of the study which will shorten the period of time for it. But we do not have authorization to do that at the present time, that's the best answer I can give you.

BIOLOGICAL CONSIDERATIONS RELATED TO FRESHWATER INTRODUCTION IN COASTAL LOUISIANA

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ABSTRACT

Louisiana has experienced a rapid loss of coastal wetlands due to natural processes such as subsidence and erosion, as well as man's engineering activities including leveeing, channelization and petroleum exploration. These activities have led to a reduction in overbank flooding and natural distributary flow which historically provided fresh water, sediments and nutrients to estuarine areas. In addition, construction of large navigation channels has caused progressive intrusion of saline waters. This has resulted in conversion of fresh, intermediate and brackish marshes to intermediate, brackish and saline marshes, respectively, as well as loss of some areas of wooded swamp. Saltwater intrusion and loss of wetlands have adversely affected productivity of wildlife and fishery resources and have led to declines in populations of waterfowl, furbearers and important shellfish and finfish species. Influx of saline waters is particularly harmful to the American oyster, due to increased predation. Juvenile stages of shrimp, menhaden and blue crabs are estuarine-dependent and utilize nearshore estuaries and adjacent wetlands as nursery areas. One way to ameliorate loss of wetland nursery areas and rate of saltwater intrusion is timely introduction of fresh water to provide sediments and nutrients vital to coastal wetlands. Major constraints to freshwater introduction in Louisiana are poor water quality and lower temperatures in the Mississippi River as compared to adjacent estuaries.

INTRODUCTION

Louisiana is experiencing a rapid loss of wetlands, including bottomland hardwood forests, wooded swamps and coastal marshes. Gagliano and van Beek (1970) reported that coastal Louisiana is experiencing a net land loss in excess of 16.5 square miles per year. These land losses have occurred as a result of natural processes, as well as man's engineering activities. Natural processes of subsidence, compaction and erosion have converted large areas of coastal marshes to open water (Morgan 1973).

Construction of major navigation channels and oil exploration canals have also been responsible for loss of large areas of wetland habitat. An example is the Mississippi River-Gulf Outlet, a 78-mile-long channel which runs from New Orleans to the Gulf of Mexico. Channel excavation, dredged material disposal and bank erosion associated with this channel have caused the direct loss of over 24,000 acres of forested wetlands, coastal marsh and associated shallow estuarine waters (U.S. Fish and Wildlife Service 1980). Leveeing of the Mississippi River has disrupted historical processes of overbank flooding and distributary flow, thereby depriving coastal marshes of fresh water, nutrients and sediments. Reduced freshwater inflows, in combination with navigation channels, have resulted in saltwater intrusion and a reduction in quality of existing marsh habitat.

Serious declines in swamp and marsh habitat have resulted in severe impacts on fish and wildlife resources and it is anticipated that these losses will continue in the future. Reduction in habitat has led to decreases in populations of wildlife, including resident and migratory waterfowl, wading birds, shorebirds, furbearers and a variety of small and big game animals. These losses have led to decreases in commercial fur harvest and reduced opportunities for activities such as waterfowl, big game and small game hunting.

Saltwater intrusion has caused drastic changes in plant and animal communities. Fresh-intermediate marshes have been converted to more saline types and some areas of wooded swamp have been entirely eliminated. These changes in habitat types have seriously altered the structure of wildlife communities. Conversion of fresh-intermediate marshes to more saline types has resulted in elimination of valuable waterfowl habitat and has also reduced populations of important furbearers such as muskrat (Ondatra zibethica) and nutria (Myocastor coypus).

Loss of coastal marshes has also adversely impacted the production of fish and shellfish species. In coastal Louisiana, the majority of commercially important fish and shellfish species are estuarine-dependent, with juveniles utilizing the estuaries as nursery areas. Marshes provide a source of organic detritus, a vital component of the estuarine food web; the importance of marsh vegetation as a source of organic detritus has been well documented (Darnell 1961, Odum et al. 1973).

Increases in salinity levels in Louisiana estuaries have reduced availability of low salinity nursery habitat important to penaeid shrimp (Penaeus spp.), blue crabs (Callinectes sapidus), Atlantic croakers (Micropogon undulatus) and menhaden (Brevoortia spp.). Saltwater intrusion has also eliminated habitat important to the American oyster (Crassostrea virginica). Salinities exceeding 12-15 ppt permit the southern oyster drill (Thais haemostoma) and other oyster predators to move in over oyster reefs. In addition, saltwater intrusion has caused areas suitable for oyster cultivation to shift inland and closer to sources of pollution. This has led to more frequent oyster reef closures by public health officials.

In order to ameliorate these problems, the New Orleans District of the U.S. Army Corps of Engineers has undertaken studies to investigate the diversion of fresh water from the Mississippi River to coastal areas of Louisiana. Two prominent studies being undertaken are entitled "Mississippi-Louisiana Estuarine Areas Study" (MLEA) and the "Louisiana Coastal Area Study" (LCA). The MLEA study area is located in southeastern Louisiana, southern Mississippi, and southwestern Alabama. The 4,700-square mile area extends from Dauphin Island, Alabama, on the eastern end of Mississippi Sound, to the east bank of the Mississippi River between Bayous Manchac and Terre Aux Boeufs in southeastern Louisiana. The LCA study area encompasses that part of the Mississippi River Deltaic Plain located in southern Louisiana, exclusive of the active Mississippi Delta, extending from the Atchafalaya River on the west to Breton Sound on the east. A map of the two study areas may be seen in Figure 1.

STUDY OBJECTIVES AND IMPACTS OF FRESHWATER DIVERSION MEASURES

Planning objectives to be satisfied by freshwater diversion measures include creation and restoration of coastal wetlands, enhancement of vegetative growth, creation of favorable salinity gradients (5-15 ppt) and increases in productivity of fish and wildlife resources.

BENEFICIAL IMPACTS

FISHERY RESOURCES

Fishery resources will be benefitted by reduction in saltwater intrusion which will increase availability of nursery habitat with favorable salinity regimes. Sediment and nutrient input resulting from freshwater diversion will serve to decrease marsh loss and enhance vegetation growth. Increases in nutrient input will also increase production of phytoplankton and zooplankton populations, which are highly important in the estuarine food web. Increases in acreage of marsh and vegetative biomass will benefit fisheries production by increasing production of organic detritus. The majority of finfish and shellfish species of commercial and recreational importance are estuarine-dependent, utilizing inshore estuaries as nursery areas. Juveniles of estuarine-dependent species move into estuarine nursery areas, and taking advantage of low salinities, elevated water temperatures and abundant food, grow very rapidly during the warm spring and summer months. The value of shallow marsh nursery areas for estuarine-dependent species has been well documented. Studies by Rogers (1979) and Simoneaux (1979) in the Upper Barataria Basin have shown such areas to be of value to juvenile Atlantic croaker and menhaden, respectively. White and Boudreaux (1977) conducted studies which demonstrate the importance of shallow marsh areas in Louisiana for brown shrimp (Penaeus aztecus) and white shrimp (Penaeus setiferus). Turner (1979) reported that inshore shrimp catches in Louisiana are directly proportional to the area of intertidal wetlands and not related to mere areal extent of estuarine waters. More (1969) documented the value of marsh habitat for blue crabs. Studies in Texas have shown the value of shallow marsh waters as habitat for immature sand seatrout (Cynoscion arenarius) and southern flounder (Paralichthys lethostigma) (Conner and Truesdale 1973).

The value of freshwater inflow has been historically demonstrated. Viosca (1938) reported the 1937 opening of the Bonnet Carre' Spillway resulted in beneficial effects on oysters, saltwater finfishes and penaeid shrimp. Gunter (1950) reported the 1945 and 1950 openings

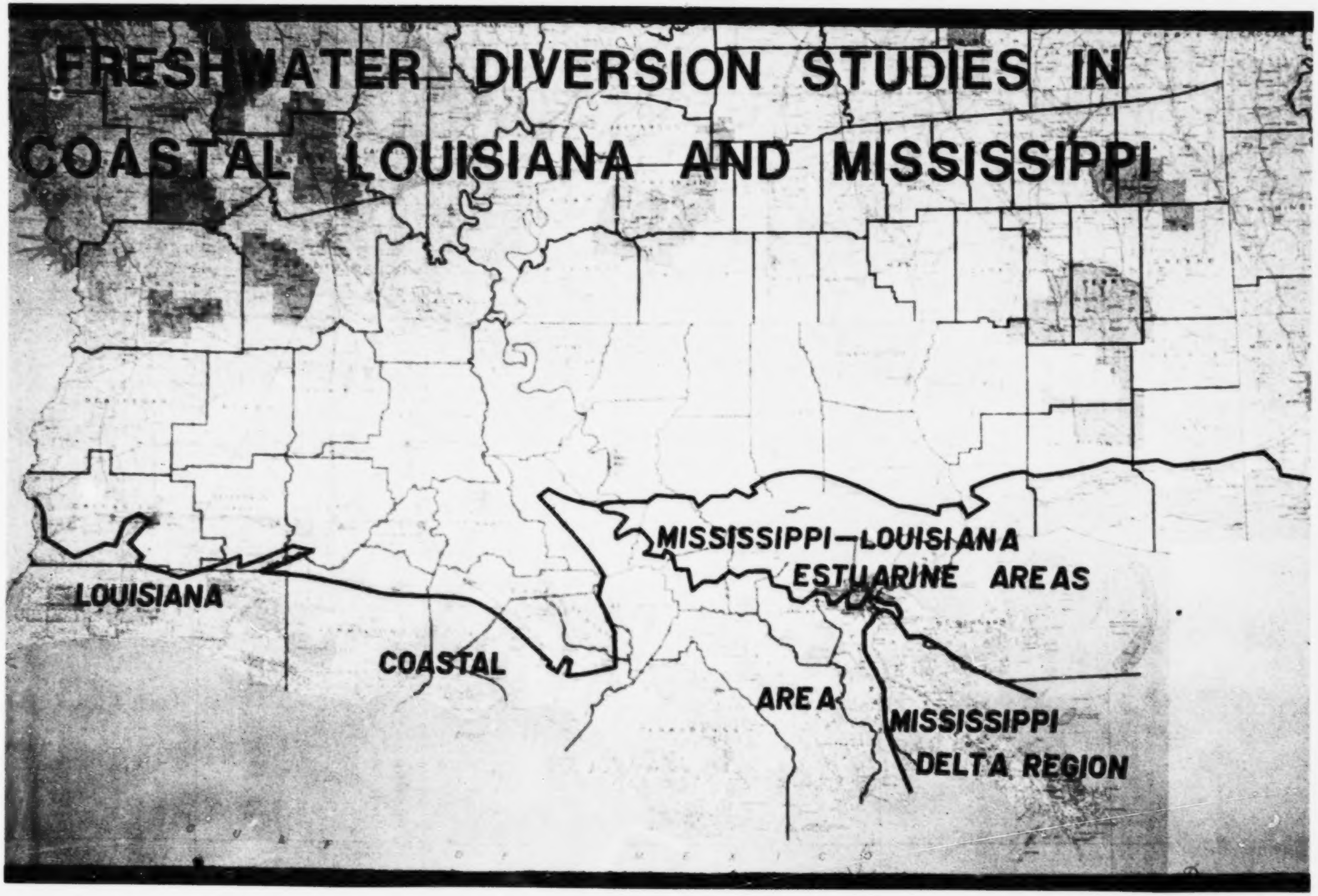
FRESHWATER DIVERSION STUDIES IN
COASTAL LOUISIANA AND MISSISSIPPI
MISSISSIPPI-LOUISIANA
ESTUARINE AREAS
LOUISIANA
COASTAL
AREA
MISSISSIPPI
DELTA REGION

Figure 1. Study areas for the Mississippi-Louisiana Estuarine Areas study and the Louisiana Coastal Area Study.

exerted overall beneficial effects on oysters. Although oyster mortalities occurred in the immediate area affected by flooding, increased production occurred in areas further removed due to nutrients introduced by river water and elimination of oyster predators by reduced salinity. Dugas (1977) reported that increased freshwater inflow in Hydrologic Unit II of coastal Louisiana during 1973, 1974 and 1975 was responsible for increased oyster production.

WILDLIFE RESOURCES

Freshwater introduction would benefit wildlife resources as well. Productivity of wildlife resources in any area is directly dependent upon habitat quality of the area. Generally speaking, wooded swamps and fresh-intermediate marshes are significantly more productive than salt marsh for the majority of wildlife species of commercial and recreational importance. Data demonstrating the value of the various marsh types for commercial fur harvest and sport hunting potential are given in Table 1. Introduction of fresh water from the Mississippi River will preserve and restore wooded swamps and fresh-intermediate marshes by reducing salinity levels. In addition, production of vegetation will be enhanced by nutrient-rich river water. The fact that Mississippi River water contains a higher level of nutrients than adjacent estuaries has been documented by Ho and Barrett (1975).

ADVERSE IMPACTS

FISHERY RESOURCES

Impacts of freshwater introduction upon fishery resources would not be entirely beneficial. Major fishery-related problems due to freshwater diversion in Louisiana are poor water quality and relatively lower water temperatures in the Mississippi River as compared to the adjacent estuaries.

The Mississippi River receives industrial wastes, runoff from agricultural lands and municipal sewage from numerous sites located upstream from and within the study area. As a result, water quality in the river is generally poor, and levels of various pollutants in the river are significantly higher than those found in the areas which would receive diverted river water. Table 2 is a comparison of levels of selected parameters in the river and various receiving bodies in the MLEA study area. Fecal coliform levels are high in the river. Highest concentrations occur downstream from Baton Rouge and New Orleans at Plaquemine and Violet, Louisiana, respectively, where average concentrations of fecal coliform bacteria are 1,000 and 3,100 colonies per 100 milliliters (Wells 1980). Discharge of river waters through existing structures has historically led to closure of oyster grounds by public health officials. However, increased production of oysters due to well planned introduction of fresh water should outweigh effects of lost harvest due to occasional closing of fishing grounds. Heavy metals, phenols, pesticides and polychlorinated biphenyls are also often present at unacceptable levels in the river. However, it is conceivable that pollution problems due to industrial waste and municipal sewage will be lessened in the future due to improved treatment facilities.

Mississippi River waters are generally about 5°C colder than adjacent estuarine waters during the

Table 1. Value per acre of commercial fur harvest and sport hunting potential by marsh type in coastal Louisiana.

	MARSH TYPE		
ACTIVITY	Fresh-Intermediate	Brackish	Saline
Fur Harvest			
Muskrat	$ 0.30	$ 0.29	$ 0.07
Nutria	2.03	0.44	Insignificant
Mink	0.01	0.01	Insignificant
Otter	0.02	0.01	Insignificant
Raccoon	0.06	0.05	Insignificant
TOTAL	$ 2.42	$ 0.80	$ 0.07
Sport Hunting			
Deer	$ 6.22	$ 0.73	$ 0.03
Rabbit	1.00	0.85	0.21
Waterfowl	19.98	15.70	0.74
Rails and Snipe	1.33	1.33	1.76
TOTAL	$28.53	$18.61	$ 2.74

Source: U.S. Fish and Wildlife Service, Lafayette, Louisiana (1980).

Table 2. Comparison of levels of selected parameters in the Mississippi River and major receiving bodies for the Mississippi-Louisiana estuarine areas study.

Environmental Protection Agency Marine Water Criteria		Mississippi River Between Bayous Manchac and Terre Aux Boeufs		Lakes Pontchartrain and Borgne, The Rigolets, and Chef Menteur Pass		Chandeleur Sound	
Parameter (ug/l)	Criteria	Mean	% Violations	Mean	% Violations	Mean	% Violations
Cadmium	5.0	3.148	7.3	1.579	7.8	0.489	0
Mercury	0.1	0.259	61.4	0.075	38.0	0.030	10.6
Copper	NC	35.140	-	11.952	-	5.013	-
Nickel	NC	13.430	-	4.870	-	3.087	-
Zinc	NC	79.930	-	21.490	-	35.218	-
PCB's	0.001	0.004	4.2	0.001	1.2	0.000	0
Phenols	1.0	2.489	41.1	2.270	44.4	1.396	34.0
Dieldrin	0.003	0.002	20.8	0.000	0	0.000	0
Endrin	0.004	0.001	12.0	0.000	0	0.000	0

Source: National Water Data Storage and Retrieval System (STORET).

NC: No EPA Criteria

early spring when juveniles of most estuarine-dependent species begin moving into Louisiana estuaries. Cooler temperature of diverted fresh waters, as well as synergistic effects of temperature and salinity, could adversely affect growth and survival of these populations. Venkataramaiah et al. (1974) conducted a series of laboratory experiments with brown shrimp which clearly demonstrated effects of interaction between salinity and temperature. Barrett and Gillespie (1973) reported that the total number of hours of water temperature below 20°C after the first week in April appeared to be a critical factor influencing brown shrimp production in Louisiana. Juvenile brown shrimp survive and grow best at salinities ranging from 15-20 ppt; discharge of cooler river waters during periods of rising salinities and temperatures could lower temperatures and salinities enough to significantly reduce production of brown shrimp. Oysters can also be adversely affected by synergistic effects of salinity and temperature. Salinities below 5 ppt when temperatures are below 20°C do not significantly harm oysters. However, prolonged periods of salinities less than 5 ppt when temperatures exceed 20°C can lead to high mortalities (Lindall et al. 1972).

WILDLIFE RESOURCES

Primary adverse impacts on wildlife resources would result from excavation and dredged material disposal due to construction of diversion channels. It is estimated that a typical diversion channel would require a right-of-way approximately 500 feet wide for the channel itself, berms, levees and disposal area. Habitat types which would be impacted include bottomland hardwood forests, wooded swamps and marshes. Diversion routes under investigation under the MLEA and LCA studies range in length from 4 to 65 miles.

CONCLUSIONS

It is acknowledged that the concept of freshwater diversion is not without problems; however, certain measures could be taken to lessen the severity of some of the negative impacts. Adverse impacts on fisheries resources could be minimized by careful planning of the design and operation of diversion structures. If possible, water should be diverted at a site in the river where pollution is minimal; however, this may not be feasible from an engineering standpoint. Benefits would be optimized by diverting water in late winter and early spring before the majority of juvenile organisms have moved into nursery areas. Also, diversion structures should be located far enough from receiving water to allow solar heating of diverted water. Maximum heating could be obtained by allowing overland flow through marshes. This would have the additional benefit of stabilizing nutrient concentrations and reducing levels of toxic substances. Intensive water quality monitoring of released water and receiving water would be necessary through at least two growing seasons. If high pollution levels are observed in the river, control structures could be closed until water quality improved. Animal and plant tissues should be analyzed to determine the degree of bioaccumulation of toxic substances.

It is evident that coastal Louisiana is experiencing severe problems resulting from loss of coastal wetlands and saltwater intrusion, and that freshwater diversion is one of the primary measures which could be used to alleviate these problems. Positive and negative aspects of the measure must be carefully weighed. At the present time, it is the general consensus of the agencies responsible for regulation and management of fish and wildlife resources in coastal Louisiana, as well as the public, that overall benefits would outweigh negative impacts.

ACKNOWLEDGEMENTS

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LITERATURE CITED

Barrett, B. B.; Gillespie, M.C. Primary factors which influence commercial shrimp production in coastal Louisiana. Louisiana Wildlife and Fisheries Commission. Oysters, Water Bottoms, and Seafoods Division, Technical Bulletin 9; 1973; 28p.

Conner, J.V.; Truesdale, F. M. Ecological implications of a freshwater impoundment in a low-salinity marsh. Chabreck, R.H., ed. Proceedings of the Coastal Marsh and Estuary Management Symposium. Baton Rouge, LA: Louisiana State University; 1973; 259-276.

Darnell, R. M. Trophic spectrum of an estuarine community based on studies of Lake Ponchartrain, Louisiana. Ecology 42: 553-568; 1961.

Dugas, R. J. Oyster distribution and density on the productive portion of state seed grounds in southeastern Louisiana. Louisiana Department of Wildlife and Fisheries, Seafood Division, Technical Bulletin 23; 1977; 27p.

Gagliano, S.M.; van Beek, J.L. Geologic and geomorphic aspects of deltaic processes, Mississippi delta system. Hydrologic and geologic studies of coastal Louisiana. Baton Rouge: Coastal Studies Institute and Department of Marine Sciences, Louisiana State University 1: 1-140; 1970.

Gunter, G. The relationship of the Bonnet Carre Spillway to oyster beds in Mississippi Sound and the "Louisiana Marsh," with a report on the 1950 opening. Publications of the Institute of Marine Science, University of Texas 3: 17-77; 1950.

Ho, C.L.; Barrett, B.B. Distribution of nutrients in Louisiana's coastal waters influenced by the Mississippi River. Louisiana Wildlife and Fisheries Commission, Oysters, Water Bottoms and Seafoods Division, Technical Bulletin 17; 1975; 39p.

Lindall, W.N., Jr.; Hall, J.R.; Sykes, J.E.; Arnold, E.L., Jr.

Louisiana coastal zone: analyses of resources and resources development needs in connection with estuarine ecology. Sections 10 and 13 -- fishery resources and their needs. Prepared by National Marine Fisheries Service Biological Laboratory, St. Petersburg Beach, Florida, for Department of the Army, New Orleans District, Corps of Engineers, Contract No. 14-17-002-430; 1972; 323p.

More, W.R. A contribution to the biology of the blue crab (Callinectes sapidus Rathbun) in Texas, with a description of the fishery. Texas Parks and Wildlife Department, Technical Series No. 1; 1969; 31p.

Morgan, J.P. Impact of subsidence and erosion on Louisiana coastal marshes and estuaries. Chabreck, R.H., ed. Proceedings of the Coastal Marsh and Estuary Management Symposium. Baton Rouge, LA: Louisiana State University; 1973; 217-233.

Odum, W.E.; Zieman, J.C.; Heald, E. J. The importance of vascular plant detritus to estuaries. Chabreck, R.H., ed. Proceedings of the Coastal Marsh and Estuary Management Symposium. Baton Rouge, LA: Louisiana State University; 1973; 91-114.

Rogers, B.D. The spatial and temporal distribution of Atlantic croaker Micropogon undulatus, and spot, Leiostomus xanthurus, in the upper drainage basin of Barataria Bay, Louisiana. Baton Rouge, LA: Louisiana State University; 1979; 96p. M.S. Thesis.

Simoneaux, L.F. The distribution of menhaden, genus Brevoortia, with respect to salinity, in the upper drainage basin of Barataria Bay, Louisiana, Baton Rouge, LA: Louisiana State University; 1979; 96p. M.S. Thesis.

Turner, R. E. Louisiana's coastal fisheries and changing environmental conditions. Day, J.W., Jr.; Culley, D.P., Jr.; Turner, R.E.; Mumphrey, A.J., Jr., eds. Proceedings of the Third Coastal Marsh and Estuary Management symposium. Baton Rouge, LA: Louisiana State University; 1979; 363-370.

U.S. Fish and Wildlife Service. A planning aid report on the Mississippi and Louisiana estuarine areas study. Prepared by the U.S. Fish and Wildlife Service Division of Ecological Services, Lafayette, Louisiana, for the U.S. Army Corps of Engineers, New Orleans District; 1980; 86p.

Venkataramaiah, A.; Lakshmi, G.J.; Gunter, G. Studies on the effects of salinity and temperature on the commercial shrimp. Penaeus aztecus Ives, with special regard to survival limits, growth, oxygen consumption, and ionic regulation. Prepared for U.S. Army Engineers Waterways Experiment Station, Vicksburg, Mississippi, Contract Report H-74-2; 1974; 134p.

Viosca, P., Jr. Effect of the Bonnet Carre Spillway on fisheries. Louisiana Conservation Review 6:51-53; 1938.

Wells, F. Hydrology and Water Quality for the Lower Mississippi River. Prepared by United States Geological Survey for the Louisiana Department of Transportation and Development, Office of Public Works, Technical Report 21; 1980; 83p.

White, C. J.; Boudreaux, C.J. Development of an areal management concept for gulf penaeid shrimp. Louisiana Wildlife and Fisheries Commission, Oysters, Water Bottoms, and Seafoods Division, Technical Bulletin 22; 1977; 77p.

EFFECTS OF WETLAND CHANGES ON THE FISH AND WILDLIFE RESOURCES OF COASTAL LOUISIANA

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ABSTRACT

The vast wetlands of the Louisiana Coastal Region (LCR) are of national importance to fish and wildlife. These wetlands winter one-fourth of the North American dabbling duck population, a large portion of the Mississippi Flyway's diving ducks, and over 400,000 geese. Coastal Louisiana also supports numerous other migratory birds, many of which nest in its wetlands. The LCR marshes produce the largest fur harvest in North America, and support the largest volume of estuarine-dependent fish and shelfish landings in the United States. Fish and wildlife-related recreation in the LCR is also extensive, including 11.9 million man-days of saltwater fishing and crabbing in 1975 and 676,000 man-days of waterfowl hunting during the 1977-1978 season. Prior studies documented an annual land-loss rate of over 16.5 mi^2/yr (42.7 km^2 yr) in the LCR. More recent investigations indicate that this rate of wetland loss more than doubled since 1956. Wetland deterioration, which is partially attributable to natural causes, has been greatly accelerated by human influences such as navigation channel excavation, agricultural drainage, and construction of mainline Mississippi River levees that have prevented freshwater and sediment overflow into adjacent subdelta marshes. Continued wetland deterioration may lead to serious declines in estuarine-dependent fish and shellfish harvest, fur catch, waterfowl habitat, and related fish and wildlife productivity. The U.S. Fish and Wildlife Service (USFWS) has long advocated freshwater diversion for habitat improvement in the Mississippi Deltaic Plain Region and is presently participating in the evaluation of several freshwater diversion sites being investigated by the U.S. Army Corps of Engineers. Preliminary USFWS estimates indicate that the monetary value of fish and wildlife productivity can be increased by more than $4.5 million/yr with a single large-scale freshwater diversion structure that would introduce Mississippi River water into the Lake Pontchartrain-Lake Borgne Basin of southeast Louisiana. Because federally financed public works projects have played a major role in wetland deterioration in the LCR, mitigation of these losses through the federal public works program would seem appropriate.

INTRODUCTION

AREA SETTING

The Louisiana Coastal Region (LCR) contains a vast expanse of valuable wetlands. Chabreck (1972) estimated that this area contained approximately 2.5 million acres (1 million ha) of fresh to saline marsh, 1.8 million acres (0.7 million ha) of ponds and lakes, and over 125,000 acres (50,588 ha) of bayous and rivers in 1968. The LCR has been divided into two main physiographic units (Morgan 1973): the Deltaic Plain of the central and eastern portions and the Chenier Plain of the western portion (Figure 1). Both of these regions have been developed over the past 5,000 years by a series of prograding and overlapping deltaic lobes composed of sediments transported by the Lower Mississippi River and its distributaries (Morgan 1973). Both the Deltaic Plain and the Chenier Plain have been the subject of extensive ecological characterization efforts by the U.S. Fish and Wildlife Service's National Coastal Ecosystems Team. Based on Chabreck (1972) and Gosselink et al. (1979), it is estimated that 74 percent of Louisiana's coastal marches occur in the Deltaic Plain, while 26 percent are found in the Chenier Plain.

IMPORTANCE TO FISH AND WILDLIFE

FISHERIES

Louisiana leads the United States in volume of commercial fishery landings. Nearly 1.7 billion pounds (0.8 billion kg) of commercial fish and shellfish were landed in Louisiana during 1978 (National Marine Fisheries Service 1979). The bulk of this catch is composed of estuarine-dependent species including menhaden, Atlantic croaker, seatrout, spot, red drum, blue crab, brown shrimp, white shrimp, and American oyster. The LCR also supports a large recreational fishery. Approximately 580,000 persons expended over 5 million saltwater angling days in the area in 1975, spending over $35 million (U.S. Fish and Wildlife Service 1977). It has also been estimated that 6.9 million days of sport crabbing effort occurred in the LCR in 1975 (U.S. Fish and Wildlife Service 1977). Approximately 373,000 recreation days were spent sport shrimping in the LCR in 1968 (U.S. Fish and Wildlife Service 1976).

WILDLIFE

The Louisiana coastal marshes are of great importance to migratory waterfowl, wintering more than two-thirds of the entire Mississippi Flyway waterfowl population in recent years (Bellrose 1976). Palmisano (1973) noted that one-fourth of the North American puddle duck population winters in these wetlands, with peak numbers of over 5.5 million of these birds recorded during December 1970. Coastal Louisiana's wetlands also support over one-half of the continental mottled duck population, with fall populations of 75,000 to 120,000 birds reported (Bellrose 1976). Diving ducks are also abundant in the Louisiana coastal marshes and adjacent waters during the fall and winter months. More than 90 percent of the Mississippi Flyway's 870,000 lesser scaup winter in Louisiana, primarily in its coastal zone. (Bellrose 1976). In addition, nearly 38 percent of the canvasbacks that winter in the Mississippi Flyway occur in Louisiana, mostly in Six Mile and Wax Lakes of the Lower Atchafalaya Basin and Atchafalaya Delta (Bellrose 1976). Many ducks present in fall and spring are transients that utilize the LCR for

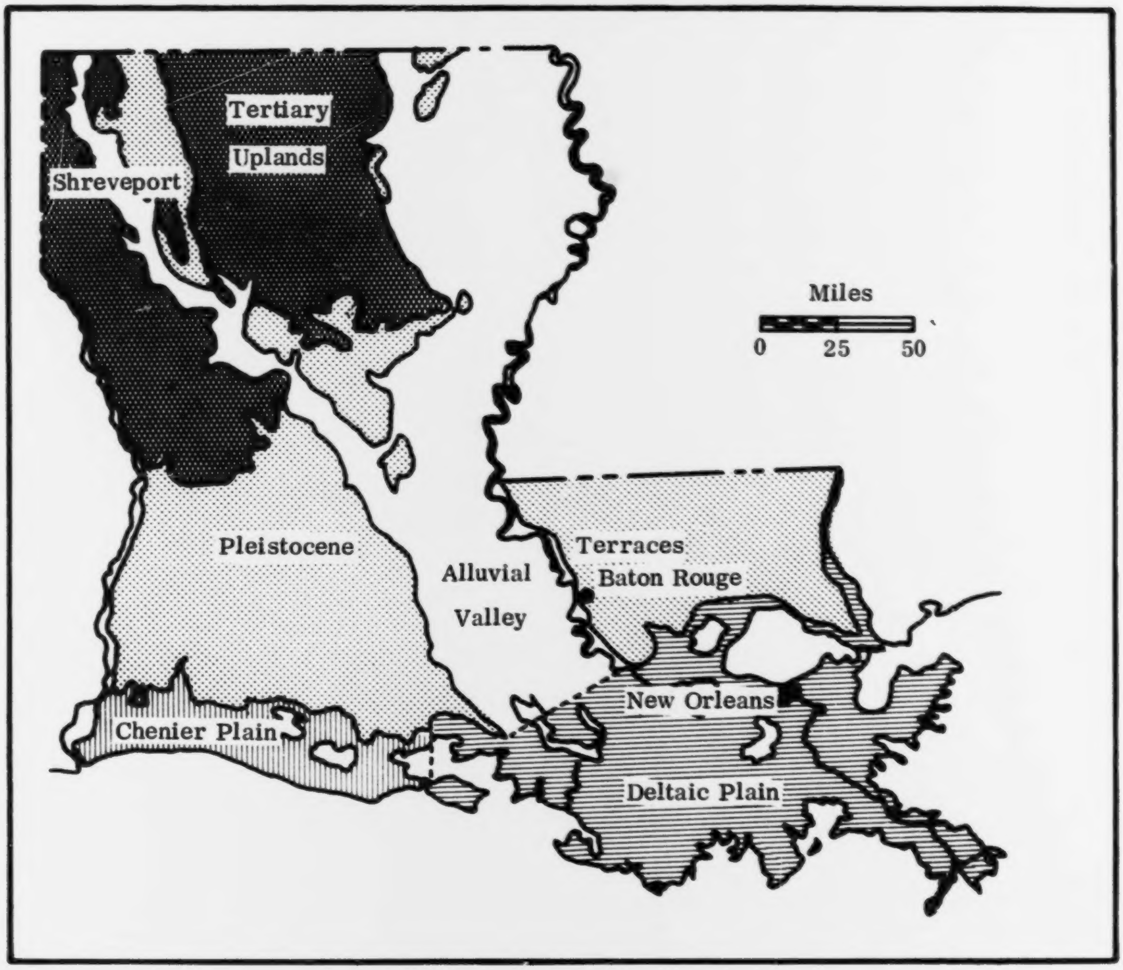
Tertiary
Uplands
Shreveport
Miles
0
25
50
Pleistocene
Alluvial
Valley
Terraces
Baton Rouge
New Orleans
Chenier Plain
Deltaic Plain

Figure 1. Physiography of Louisiana Coastal Region (adapted from Morgan 1973).

feeding and resting enroute to or from Central and South America (Palmisano 1973). The Louisiana coastal marshes and adjacent ricefields have supported 369,000 lesser snow geese and 55,000 white-fronted geese in recent years (A.R. Brazda personel communication).

The LCR wetlands provide important habitat to numerous other migratory birds. Common game species include clapper rail, king rail, sora, common snipe, purple gallinule, and common gallinule. Non-game migratory species are also abundant in the area. A total of 148 nesting colonies of seabirds, wading birds, and shorebirds representing 26 species and over 794,000 nesting adults were inventoried in the LCR during 1976 (Portnoy 1977). In addition, approximately 14 active bald eagle nests were recorded by Fish and Wildlife Service personnel in the LCR during 1980, representing the largest nesting concentration of this endangered species in the south-central United States.

Because of its extensive coastal wetlands, Louisiana has been the leading fur-producing area in North America as long as records have been kept (Lowery 1974). The Louisiana fur harvest accounted for nearly one-third of the Nation's fur take in the 1969-1970 season (U.S. Fish and Wildlife Service 1971). According to the Louisiana Department of Wildlife and Fisheries (1978b), over 3.2 million pelts worth more than $24 million were taken in Louisiana during the 1976-1977 season. Muskrat and nutria, primarily coastal species, accounted for nearly 90 percent of the pelts harvested during that period.

Alligators in the LCR exceed 300,000 (Louisiana Department of Wildlife and Fisheries 1980a), permitting controlled hunting in much of the area. In 1979, 16,300 alligators, worth approximately $1.7 million, were harvested in the LCR (Louisiana Department of Wildlife and Fisheries 1980b).

The LCR supports extensive sport hunting and other wildlife-oriented recreation. For example, an estimated 676,000 man-days were spent waterfowl hunting in the LCR during the 1977-1978 season (Louisiana Department of Wildlife and Fisheries 1978a), and the 1980 demand for consumptive wildlife-oriented recreation in the LCR has been projected at 1.14 million man-days (U.S. Fish and Wildlife Service 1976).

MAGNITUDE OF WETLAND DETERIORATION IN COASTAL LOUISIANA

Gagliano and van Beek (1970) documented a net annual land-loss rate of 16.5 mi^2 (42.7km^2) in the LCR. This estimate was based on a comparison of maps covering the periods 1931-1942 and 1948-1967. Using U.S. Geological Survey quadrangle sheets and aerial photographs for the period 1960-1974, Adams et al. (1976) established a net annual marsh-loss rate in the Barataria Basin of the LCR estimated at 3,200 to 7,416 acres (1,295 to 3,001 ha). Craig et al. (1979) compared this rate reported by Adams et al. (1976) to the 1,942 acres (786 ha) reported by Gagliano and van Beek (1970) for this area, indicating an increase in the land-loss rate of 65 percent to 282 percent over the rate reported by the latter authors. Recent studies of wetland loss have been conducted in the Chenier Plain ecosystem of southwest Louisiana and southeast Texas (Gosselink et al. 1979). Based on these studies, it was estimated that approximately 5,000 acres/yr (2,024 ha/yr) of natural and impounded marsh were converted to open water, spoil deposits, or agricultural or urban uses between 1952 and 1974 in the Vermilion, Chenier, Mermentau, and Calcasieu basins of southwest Louisiana and the Sabine Basin of southwest Louisiana and southeast Texas.

A recent study (Wicker 1980) of the Mississippi Deltaic Plain Region (MDPR) conducted for the Fish and Wildlife Service's National Coastal Ecosystems Team and the U.S. Bureau of Land Mangement has produced alarming statistics. Preliminary analysis of data obtained from planimetering habitat maps prepared for this study revealed that approximately 464,500 acres (187,983 ha) of coastal marsh were lost in the Louisiana portion of the MDPR between 1956 and 1978, for an annual loss rate of over 20,200 acres (8,175 ha) or (31.6 mi^2/yr) (Robert Ader 1980 personal communication). Combining this estimate with the estimated marsh-loss rate of 5,000 acres/yr (2,024 ha/yr) or 7.8 mi^2/yr (20.7 km^2/yr) for that portion of the Chenier Plain found in western Louisiana and extreme southeast Texas, it is estimated that the marshes of the entire LCR are being lost at an estimated rate exceeding 25,000 acres/yr (10,118 ha/yr), or over 39 mi^{2}yr (101.0 km^2/yr). This is more than twice the rate of 16.5 mi^2/yr (42.7 km^2/yr) reported by Gagliano and van Beek (1970).

CAUSES OF WETLAND DETERIORATION

Wetland deterioration in the LCR is attributed to land loss and saltwater intrusion. According to Craig et al. (1979) land loss in the LCR results from an interaction of natural and man-induced impacts. Natural land loss occurs through subsidence, compaction, and erosion of the substrate following cessation of active deltaic deposition (Morgan 1973). Barrier islands and tidal inlets buffer coastal marshes from stormy energy and regulate salinities. The erosion of barrier islands and widening of tidal inlets have also been identified as causes of land loss (Craig et al. 1979). Numerous man-induced alterations have accelerated natural wetland loss. The construction of federally financed navigation channels, mainline Mississippi River levees, and upstream diversions and flood control reservoirs have virtually eliminated overbank flooding along the Lower Mississippi River. Consequently, most of the riverborne sediments are being transported past formerly active deltas and into the deeper Gulf of Mexico (Gagliano and van Beek 1970). This loss of sediment input has, except in Atchafalaya Bay, prevented large-scale delta building and has accelerated subsidence and erosion of existing marshes. Other human causes of wetland loss include canal dredging and associated spoil disposal and drainage of wetlands for agricultural purposes (Gagliano 1973). Gagliano attributed approximately 25 percent of the total land loss in coastal Louisiana during the past 30 years to oil and gas industry dredging.

Saltwater intrusion, another major cause of wetland deterioration, is occurring in many areas of the LCR. This process has been documented at numerous locations, such as Barataria Bay (Van Sickle et al. 1976) and along the Mississippi River-Gulf Outlet in southeast Louisiana (Fontenot and Rogillio 1970). Saltwater intrusion has wide-ranging adverse effects, such as allowing encroachment of the predaceous southern oyster drill (Thais haemastoma) onto productive oyster reefs (Pollard 1973) and conversion of fresher marsh vegetation to more saline types.

FISH AND WILDLIFE IMPLICATIONS OF WETLAND DETERIORATION

FISHERIES

The marshes of the LCR are extremely important to the maintenance of its estuarine-dependent sport and commercial fisheries. These wetlands produce vast amounts of organic detritus, an important trophic component of estuarine fish and shellfish productivity (Darnell 1961; Odom et al. 1973). The marshes and associated shallow waters of the LCR are also important as nursery habitat for many estuarine-dependent species. This importance has been documented by numerous authors, such as Herke (1971), White and Boudreaux (1977), Rogers (1979), and Chambers (1980). There is growing evidence that the amount of marsh is the most important factor influencing estuarine-dependent fishery production. Turner (1979) reported that Louisiana's commercial inshore shrimp catch is directly proportional to the area of intertidal vegetation, and that the area of estuarine water does not seem to be directly associated with shrimp yields. He further noted that the loss of wetlands in Louisiana has a direct negative effect on fisheries. Although the effects are masked by large annual variations in yield, wetland losses in the LCR reported by Craig et al. (1979) are equivalent to 6.31 million pounds (2.86 million kg) of shrimp harvest "lost" over the past 20 years (Turner 1979). Lindall et al. (1972) presented evidence that shrimp and menhaden are being harvested at or near maximum sustainable yield. These species accounted for nearly 99 percent of the total volume of Louisiana's commercial fish and shellfish landings in 1976 (Plaisance 1977). Further evidence that this is occuring was presented by Harris (1973), who noted that any substantial decreases in marsh habitat will result in decreased estuarine-dependent fishery production. An analysis of the dependence of menhaden catch on wetlands in the LCR was conducted by Cavit (1979). The findings of this analysis suggest that menhaden yields are greatest in those LCR estuarine basins having the highest ratio of marsh to open water. Based on the evidence cited above, continued wetland loss in the LCR could lead to serious declines in its estuarine-dependent fishery.

WILDLIFE

Wildlife dependent on the LCR marshes face serious habitat declines as a result of future land loss and saltwater intrusion. Losses of fresh to intermediate marsh (Chabreck 1972) or conversion of these wetlands to more saline types will adversely affect migratory puddle ducks, as relative abundance of these waterfowl in the LCR is highest in these marsh types (Palmisano 1973). Based on rather conservative projections of declines in habitat quality and abundance in the LCR, it has been estimated that demand for waterfowl hunting will exceed available supply by 454,000 man-days by the year 2020 (U.S. Fish and Wildlife Service 1976). Habitat quality and quantity for other marsh birds will also be reduced by continued wetland deterioration. Nutria comprised roughly 70 percent of Louisiana's total fur harvest between 1970 and 1975 (O'Neil and Linscombe 1975). Palmisano (1973) reported that nutria catch per acre is highest in fresh marsh, declining progressively in the intermediate, brackish, and saline marsh types. Alligator populations also reach peak levels in fresh to intermediate marshes (Palmisano et al. 1973). Accordingly, continued wetland deterioration can be expected to result in declines in fur harvest and alligator populations, especially as land loss and salinity intrusion reduce fresher marsh acreage.

DISCUSSION OF MEASURES TO REDUCE WETLAND DETERIORATION

Except for regulation of development, the primary measures investigated to date for control of wetland deterioration in the LCR have involved diversion of Mississippi River water into adjacent marshes and estuarine areas for salinity control and creation of new subdeltas. A plan for introduction of Mississippi River water into the subdelta marshes of southeast Louisiana was submitted by the U.S. Fish and Wildlife Service to the U.S. Army Corps of Engineers in 1959 (U.S. Fish and Wildlife Service 1959). This plan included a recommendation for the construction of four water control structures, having a combined discharge capacity of 24,000 cubic feet per second (cfs), to divert Mississippi River water for salinity control. The structures would have benefitted an estimated 264,500 acres (107,043 ha) of marsh and estuarine waters. The annual benefits of this plan in increased oyster yields, furbearer harvest, and waterfowl utilization were estimated at $841,600, exceeding costs by 62 percent. Recognizing that the project was necessary to partially rectify wetland degradation brought about by the construction of federally financed Mississippi River mainline levees, the U.S. Fish and Wildlife Service (1959) recommended that the Mississippi River and Tributaries Project authorized by the Flood Control Act of 1928 be amended to recognize fish and wildlife as a project purpose and to include the service's freshwater introduction plan as an integral feature. That plan, now known as the "Mississippi Delta Region, Louisiana," project, was authorized by Public Law 89-298 on October 27, 1965. Detailed planning of one of the four authorized diversion structures was initiated in 1969, but was suspended when local interests failed to furnish economic justification for their requested change in the location of that structure (U.S. Army Corps of Engineers 1975). It should be noted that, despite the obvious need for the project to mitigate the adverse effects of the Mississippi River mainline levees, the project is classified as "enhancement," making local interests responsible for 25 percent of the project costs. This has been cited by local interests as one reason for their reluctance to participate in the project.

The most comprehensive treatment of measures for arresting land loss and salinity intrusion in the LCR is contained in a report prepared by Gagliano et al. (1973b) under contract to the U.S. Army Corps of Engineers. That study was conducted in conjunction with a broad evaluation of the LCR by an *ad hoc* interagency group and evaluated two primary measures for addressing wetland deterioration, including:

(1) controlled introduction of Mississippi River water into adjacent estuarine marshes and bays for salinity control and nutrient input; and

(2) creation of subdeltas along the lower Mississippi River through controlled freshwater diversion into adjacent shallow bays.

A multi-use management plan for south-central Louisiana was subsequently developed (Gagliano et al. 1973a). This plan recommended certain developmental controls, management and maintenance of barrier islands, erosion control, and surface water management including supplemental freshwater introduction, management of existing runoff surpluses and controlled subdelta building with diverted Mississippi River water and sediments.

Despite the virtually universal recognition of the seriousness of the wetland deterioration problem in the LCR and the existence of plans to address that problem, no major federally financed measures have been implemented. However, two ongoing federal water resource studies being conducted under the leadership of the U.S. Army Corps of Engineers offer considerable promise for large-scale supplemental freshwater introduction into the subdelta marshes of the LCR. These include the Louisiana Coastal Area Study and Mississippi and Louisiana Estuarine Areas Study. With regard to the latter study, preliminary estimates by the U.S. Fish and Wildlife Service indicate that between $4.4 and $5.2 million in annual benefits to fish and wildlife can be realized with a single large-scale diversion into the Lake Pontchartrain-Lake Borgne area of southeast Louisiana (Fruge and Ruelle 1980).

In 1979, the Louisiana Legislature enacted legislation directing the Secretary of the Louisiana Department of Transportation and Development to prepare a freshwater diversion plan for Louisiana. That plan is expected to complement any freshwater introduction measures implemented by Federal agencies.

CONCLUSIONS AND RECOMMENDATIONS

It is clear that the important fish and wildlife resources of the LCR are threatened by rapid, continued degradation of its wetland habitat through land loss and saltwater intrusion. This problem is widely recognized by natural resource managers, scientists, and the public at large, and positive measures have been proposed to address it. However, definitive action must be taken to implement these measures at the earliest possible date. Because federally constructed flood control and navigation works have played a major role in the deterioration of Louisiana's coastal wetlands, it would seem that mitigation of these adverse impacts should be accomplished primarily through the public works programs of the Federal Government.

LITERATURE CITED

Adams, R. D.; Barrett, B. B.; Blackmon, J. H.; Gane, B. W.; McIntire, W. G. Barataria Basin: geologic processes and framework. Baton Rouge, LA: Louisiana State Univ., Center for Wetland Resources; Sea Grant publication no. LSU-T-76-006 1976; 117p.

Ader, R. U.S. Fish and Wildlife Service, National Coastal Ecosystems Team; Personal communication; 1980 August 12.

Bellrose, F.C. Ducks, geese and swans of North America. A Wildlife Management Institute book sponsored jointly with Illinois Natural History Survey. Harrisburg, PA: Stackpole Books; 1976: 543 p.

Brazda, A.R. U.S. Fish and Wildlife Service, Office of Migratory Bird Management; Personal communication; 1981 March 16.

Cavit, M.H. Dependence of menhaden catch on wetland habitats: a statistical analysis. NSTL Station, MS: U.S. Fish and Wildlife Service, Office of Biological Services, National Coastal Ecosystems Team; 1979; 12 p. Unpublished report submitted to U.S. Fish and Wildlife Service, Ecological Services Field Office, Lafayette, LA.

Chabreck, R.H. Vegetation, water and soil characteristics of the Louisiana coastal region. Baton Rouge, LA: Louisiana State Univ. Agricultural Experiment Station. 1972; 72 p. Bulletin No. 664.

Chambers, D. G. An analysis of nekton communities in the upper Barataria Basin, Louisiana. Baton Rouge, LA: Louisiana State Univ.; 1980. 286 p. Thesis.

Craig, N. J.; Turner, R. E.; Day, J. W., Jr. Land loss in coastal Louisiana. Day, J.W., Jr.; Culley, D. D., Jr.; Turner, R.E.; Mumphrey, A. J., Jr., eds. Proceedings of the third coastal marsh and estuary management symposium; 1978 March 6-7; Louisiana State Univ., Baton Rouge, LA. Louisiana State Univ. Division of Continuing Education, 1979: 227-254.

Darnell, R. M. Trophic spectrum of an estuarine community based on studies of Lake Pontchartrain, Louisiana. Ecology 42(3): 553-568; 1961.

Fontenot, B. J., Jr.; Rogillio, H. E. A study of estuarine sportfishes in the Biloxi Marsh Complex, Louisiana. F-8 Completion Report, a Dingell-Johnson Project. Baton Rouge, LA: Louisiana Wild Life and Fisheries Commission; 1970; 172 p.

Fruge, D. W.; Ruelle, R. Mississippi and Louisiana Estuarine Areas Study. A planning-aid report submitted to the U.S. Army Corps of Engineers, New Orleans District, New Orleans, Louisiana. Lafayette, LA: U.S. Fish and Wildlife Service, Division of Ecological Services; 1980; 86 p.

Gagliano, S. M. Canals, dredging, and land reclamation in the Louisiana coastal zone. Hydrologic and geologic studies of coastal Louisiana. Baton Rouge, LA: Coastal Resources Unit, Center for Wetland Resources, Louisiana State Univ., 1973; 104 p. Report no. 14.

Gagliano, S. M.; Culley, P.; Earle, D. W., Jr.; King, P.; Latiolais, C.; Light, P.; Rowland, A.; Shlemon, R.; van Beek, J. L. Environmental atlas and multiuse management plan for south-central Louisiana. Hydrologic and geologic studies of coastal Louisiana. Baton Rouge, LA:

Center for Wetland Resources, Louisiana State Univ., 1973a; 132 p. Report No. 18, Vol. 1.

Gagliano, S. M.; Light, P.; Becker, R. E. Controlled diversions in the Mississippi Delta System: an approach to environmental management. Hydrologic and geologic studies of coastal Louisiana. Baton Rouge, LA: Coastal Resources Unit, Center for Wetland Resources Unit, Louisiana State Univ., 1973b; 146 p. Report No. 8.

Gagliano, S. M.; van Beek, J. L. Geologic and geomorphic aspects of deltaic processes, Mississippi Delta System. Hydrologic and geologic studies of coastal Louisiana. Baton Rouge, LA: Coastal Resources Unit, Center for Wetland Resources, Louisiana State Univ., 1970; 140 p. Report no. 1.

Gosselink, J.G.; Cordes, C.L.; Parsons, J.W. An ecological characterization study of the Chenier Plain coastal ecosystem of Louisiana and Texas. Slidell, LA: U.S. Fish and Wildlife Service, Office of Biological Services; 1979. 3 vol. FWS/OBS 78/9 through 78/11.

Harris, A. H. Louisiana estuarine-dependent commercial fishery production and values (regional summary and WRPA-9 and WRPA-10 analysis of production and habitat requirements). Report prepared for U.S. Department of Commerce, National Marine Fisheries Service, Water Resources Division, St. Petersburg, FL: 1973; 36 p. Available from: National Marine Fisheries Service, St. Petersburg, FL.

Herke, W. H. Use of natural, and semi-impounded, Louisiana tidal marshes as nurseries for fishes and crustaceans. Baton Rouge, LA: Louisiana State Univ.; 1971. Available from: University Microfilms, Ann Arbor, MI; Publication no. 71-29,372. 264 p. Dissertation.

Lindall, W. N., Jr.; Hall, J. R.; Sykes, J. E.; Arnold, E. L., Jr. Louisiana coastal zone: analyses of resources and resource development needs in connection with estuarine ecology. Sections 10 and 13--fishery resources and their needs. St. Petersburg Beach, FL: National Marine Fisheries Service Biological Laboratory; 1972; 323 p. Prepared for U.S. Department of the Army, New Orleans District, Corps of Engineers, Contract no. 14-17-002-430.

Louisiana Department of Wildlife and Fisheries. 1977-78 waterfowl survey. Baton Rouge, LA: 1978a. 12 p.

Louisiana Department of Wildlife and Fisheries. Wildlife resources of Louisiana. Baton Rouge, LA: 1978b; 34 p. Wildlife education bulletin no. 93.

Louisiana Department of Wildlife Fisheries. Alligator regulations adopted by Louisiana Wildlife and Fisheries Commission at its regular meeting held in New Orleans, Louisiana on Tuesday, July 29, 1980. New Orleans, LA: 1980a. 6 p. mimeograph.

Louisiana Department of Wildlife

and Fisheries. News release no. 80-48, 1980b August 8.

Lowery, G. H., Jr. Fur in Louisiana. The mammals of Louisiana and its adjacent waters. Baton Rouge, LA: Published for Louisiana Wildlife and Fisheries Commission, Louisiana State Univ. Press; 1974: 21-45.

Morgan, J. P. Impact of subsidence and erosion on Louisiana coastal marshes and estuaries. Chabreck, R. H., ed. Proceedings of the second coastal marsh and estuary management symposium; 1972 July 17-18; Louisiana State Univ., Baton Rouge, LA: Louisiana State Univ. Division of Continuing Education; 1973: 217-233.

National Marine Fisheries Service. Fisheries of the United States, 1978. Washington, D.C.: 1979; 120 p. Current Fisheries Statistics no. 7800. Available from: U.S. National Marine Fisheries Service, Washington, DC: NOAA--S/T 79-183.

Odom, W. E.; Zieman, J. C.; Heald, E.J. The importance of vascular plant detritus to estuaries. Chabreck, R. H., ed. Proceedings of the second coastal marsh and estuary management symposium; 1972 July 17-18; Louisiana State Univ., Baton Rouge, LA. Louisiana State Univ. Division of Continuing Education; 1973: 91-114.

O'Neil, T.; Linscombe, G. The fur animals, the alligator, and the fur industry in Louisiana. New Orleans, LA: Louisiana Wildlife and Fisheries Commission; 1975; 66 p. Wildlife education bulletin no. 106.

Palmisano, A. W. Habitat preference of waterfowl and fur animals in the northern gulf coast marshes. Chabreck, R. H., ed. Proceedings of the second coastal marsh and estuary management symposium; July 17-18; Louisiana State Univ., Baton Rouge, LA. Louisiana State Univ. Division of Continuing Education; 1973: 163-190.

Palmisano, A. W.;Joanen, T.; McNease, L. L. An analysis of Louisiana's 1972 experimental alligator harvest program. Paper presented at 27th annual meeting of the Southeastern Association of Game and Fish Commissioners. Hot Springs, AR.; 1973 October.

Plaisance, O. Louisiana landings, annual summary 1976. Washington, DC: National Oceanic and Atmospheric Administration, National Marine Fisheries Service; 1977; 8 p. Current Fisheries Statistics no. 7222.

Pollard, J. F. Experiments to re-establish historical oyster seed grounds and to control the southern oyster drill. New Orleans, LA: Louisiana Wild Life and Fisheries Commission, Oyster, Water Bottoms and Seafoods Division, 1973: 82 p. Technical bulletin no. 6.

Portnoy, J. W. Nesting colonies of seabirds and wading birds -- coastal Louisiana, Mississippi, and Alabama. Slidell, LA: U.S. Fish and Wildlife Service, Biological Services Program; 1977; 126 p. FWS/OBS-77/07.

Rogers, B. D. The spatial and temporal distribution of Atlantic croaker, Micropogon undulatus, and spot, Leiostomus xanthurus, in the upper drainage basin of Barataria Bay, Louisiana. Baton Rouge, LA: Louisiana State Univ.; 1979. 96 p. Thesis.

Turner, R. E. Louisiana's coastal fisheries and changing environmental conditions. Day, J. W., Jr.; Culley, D. D., Jr.; Turner, R. E.; Mumphrey, A. J., Jr., eds. Proceedings of the third coastal marsh and estuary management symposium; 1978 March 6-7; Louisiana State Univ., Baton Rouge, LA. Louisiana State Univ. Division of Continuing Education; 1979: 363-370.

U.S. Army Engineer District, Corps of Engineers, New Orleans, Louisiana. Mississippi Delta Region Salinity Control Structure, Louisiana, condition of improvement, 30 June 1975. In Project Maps, Volume 2: Flood Control, Mississippi River and Tributaries. 1975 (p. 3-17A).

U.S. Fish and Wildlife Service. A plan for freshwater introduction from the Mississippi River into sub-delta marshes below New Orleans, Louisiana, as part of the Mississippi River and Tributaries review. Atlanta, GA: 1959; 48 p. Available from: U.S. Fish and Wildlife Service, Division of Ecological Services, Lafayette, LA.

U.S. Fish and Wildlife Service. Fur catch in the United States, 1970: Washington, DC: 1971; 4p. Wildlife leaflet 499.

U. S. Fish and Wildlife Service. Fish and wildlife study of the Louisiana coastal area and the Atchafalaya Basin Floodway. Appendix D, part 3: Sport fish and wildlife harvest. Lafayette, LA: U.S. Fish and Wildlife Service, Division of Ecological Services; 1976; 61 p. Unpublished.

U. S. Fish and Wildlife Service. 1975 National Survey of hunting, fishing and wildlife associated recreation. Washington, DC: 1977; 91 p.

Van Sickle, V. R.; Barrett, B. B.; Ford, T. B.; Gulick, L. J. Barataria Basin: salinity changes and oyster distribution. Baton Rouge, LA: Center for Wetland Resources, Louisiana State Univ., 1976; 22 p. Sea Grant publication no. LSU-T-76-02.

White, C. J.; C. J. Boudreaux. Development of an areal management concept for gulf penaeid shrimp. New Orleans, LA: Louisiana Wildlife and Fisheries Commission, Oysters, Water Bottoms and Seafoods Division; 1977; 77p. Technical bulletin no. 22.

Wicker, K. M. Mississippi Deltaic Plain Region ecological characterization: a habitat mapping study. A user's guide to the habitat maps. U. S. Fish and Wildlife Service, Office of Biological Services, 1980. FWS/OBS - 79/07. 45p. + App.

DISCUSSION

Question: Mark Crandle, Coastal Management Section-Louisiana. I'd like to ask somebody from the Corps if anybody has--it seems like funding is a major problem here--attempted to get this 25 percent max that the locals have to put up changed in any way?

Answer: (from the panel) Not that I know of but that's an excellent idea. I don't think that's the only hindrance to the implementation of the plan. It would still be difficult, of course, but not impossible to construct such a site in a parish that did not want that site in that parish. I know certainly that's an area that the State of Louisiana could assist us in, either offering to cover that 25 percent, or convince local interests that they don't mind putting up the 25 percent, or if it happens to go to 100 percent Federal funding, then they ought not oppose the construction of such a site in their community.

Question: Do you have any indication of how the retention of the sediments in the Atchafalaya Bay would change if you changed the major flow from the Atchafalaya to the Wax Lake Outlet? Would there be a change in the retention there?

Answer: (from the panel) No, I just think it would change the location of deposition slightly. It's possible, yes, that it could since the reef does form sort of an impediment over on the lower Atchafalaya River side, whereas on the Wax Lake side that's not necessarily the case. But I think you would still get eventually a general fill of the bay behind the reef.

Question: Clark Lozes, Plaquemines Parish. My basic reason for attending is to find out what's happening on a national scale and to find out more about what's happening in the rest of the states. I am a little nervous so please bear with me on this. I'm not normally a public speaker, but I do have several questions. In regard to introducing fresh water into the marsh, and especially because we do have such a bad marsh, I see two basic concepts: one, we're trying to spend Federal money to improve a very small area in the whole United States. I think that this is good for the local community however, I think it can be served better. We have an area on the right descending bank of the Mississippi approximately 40 miles miles below the city of New Orleans called Empire that has a ship channel and locks. We can easily divert the flow of Mississippi water into the marsh through the locks. This is an area that needs to be studied a little bit farther before we go opening up new freshwater inflows. In addition to that at the Algiers Canal just south about mile 68 on the Mississippi River, there is the ability to take fresh-water from the river and introduce it through the bayou. This would not cost any great amount of money to do. It would require some coordination on both the U.S. Corps of Engineers, the marine biologists, and more than likely, other state agencies. One of our problems that we see is the lack of local government input. An example of this was last year when we had oyster fishing on what we call Quarantine Bay right adjacent to a bayou which is a freshwater inlet for oysters. The BODs indicated by the health department showed that the oyster reef should be shut down. The water being poured on the oyster reef was from a controlled structure put there by the Federal Government. We had closed down three other water control structures to stop BODs. It took us three and a half weeks to get the government to come down and close their water control structure. That's what we don't want to see--Federal Government interfering with the local fishermen. If it's time to close it down, Gentlemen, it's time to close it down. It's not three weeks later that affects the local fisherman. That's our biggest fear. Over any type of federally-funded projects, how much can the local community input and control the effects that are basically theirs?

Answer: (from the panel) the idea behind these projects is to, in the long term, increase the overall availability of areas suitable for things like growing oysters. Over the years the salinity intrusion has gradually shifted the areas suitable for growing oysters inland. If you really divert large amounts of freshwater from those areas they are going to be destroyed but in the long run the idea is to have a larger area available and increased overall production. But if you do have these mass amounts of freshwater diversions, you are going to wipe out some areas that presently exist. In some way those people will have to be compensated. But it's long-term, overall benefits that are being looked at. You'll have, theoretically, a much larger area available for those types of things than you do now.

Question: It's been my experience that there was little local input into most of the planning of the Corps of Engineers and other federal projects. Were local people pretty well excluded from a lot of the negotiations in this case, or was it well publicized, or what was the case?

Answer: (from the panel) I haven't been affiliated with these studies that long and I'm not even familiar with when the last public meeting was held. I know that some of the guys from Fish and Wildlife Service have been involved a lot longer than I have, and can address that, relative to when the last public meetings were held down in Plaquemines Parish. If they would be kind enough to bail me out.

Comment: Scott Nixon, Rhode Island. I can't resist after hearing all of this to make an unpopular observation. And that is when we hear there's too much freshwater over on one side, and then there's not enough on the other side and the Corps has done all this work of building dams and levees and moving the water around, we want them to build more and move it around somewhere and bail us out because we screwed that up and we've got problems with the water quality. And maybe that will work and maybe that won't, but I'm struck by hearing all of this this morning that when each of these projects was undertaken we had a glowing report as to what it was going to do for us. And yet we find afterwards that there were all sorts of fallouts that we hadn't anticipated and now we've got all kinds of other problems and we want to do another six projects to get us out of that one. And my impression from reading the literature is that we really don't understand these systems and there is a tremendously complex environment in coastal Louisiana to make a really compelling case. That we know what is going to happen if we put fresh water here, there, or somewhere else, and that some of the cost-benefit calculation that must go into doing the kinds of freshwater studies rest on the assumption of what we're going to get in terms of fisheries yields for moving the freshwater somewhere else and promoting one kind of wetland over another one. And, at least, in that area we really don't have a good case for a lot of those linkages that people are supposing are there. Somebody mentioned Gene Turner's paper today, but that's an awfully slim kind of evidence to bring forward for spending millions and millions of dollars of Federal money. So an outsider to Louisiana, I'm not all that sure that I'm anxious about having them spend all that money either.

Comment: Mark Crandle, Coastal Management. Increased production is going to be an added benefit if it exists. But what we're dealing with here is the physical loss of land, in terms of hurricane protection and many other things. That we're actually just losing land mass, whether or not it's tied to fishery productions or not. And we have to do something to address that problem specificaly. It's nice to be able to justify your problem by saying well, we're going to have more shrimp, we're going to have more oysters, and more of this. But there is a very real problem that has absolutely nothing to do with the fisheries production and that's physical protection of the coastline of Louisiana.

CHAPTER 6

FISHERIES MANAGEMENT AND FRESHWATER INFLOW

A NEW APPROACH TO DETERMINING THE QUANTITATIVE RELATIONSHIP BETWEEN FISHERY PRODUCTION AND THE FLOW OF FRESH WATER TO ESTUARIES

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ABSTRACT

Freshwater inputs to estuaries appear to enhance the production of marine organisms, because the highest marine standing stocks along shorelines are found in or near estuaries, which receive freshwater inputs. Despite this apparent connection, efforts to quantify the role of freshwater in estuarine production not only have contradicted one another but have, in some cases, been contradictory to the basic concept of the value of freshwater inflows to estuarine production. In this paper we describe the water regimes, water management problems, and related estuarine research of several distinct regions of the Gulf of Mexico, from south Texas to south Florida, and then suggest an approach to examining the role of freshwater in estuaries that could lead to a unifying principle applicable to all situations.

INTRODUCTION

Coastal areas receiving fresh water are important to the production of fish and shellfish. The relationship between freshwater inflow and production is recognized but has been difficult to quantify. Fishery managers have few guidelines and little information to evaluate the effect of water management projects on fisheries, but they must decide how much water can be diverted or how much the seasonally of flow can be altered without reducing estuarine productivity.

"Production functions" quantitatively relating fish production to freshwater flow under various circumstances are needed. Although the functions may differ for each estuary and each species, determining such functions for even one estuary would be valuable in establishing a methodology. Determining production functions for several estuaries may lead to the development of a generalized model applicable to any estuary. Such a model surely must incorporate hydrologic, meteorologic, and hydrodynamic concepts as well as physiological and ecological information and will therefore require an interdisciplinary effort.

This paper will (a) provide a brief history of scientific work done in the Gulf of Mexico that relates to this problem; (b) summarize some recent work in Florida, Louisiana, and

Texas; (c) suggest new perspectives; (d) establish the rationale for an interdisciplinary approach; and (e) present a research outline.

HISTORICAL OVERVIEW

Activities of man that affect the quantity and/or timing of the flow of fresh water to estuaries include: (1) dams for irrigation and power; (2) diversions; (3) canals in uplands; (4) deforestation; (5) clearcutting; (6) grazing; (7) road construction; and (8) paving (as in urban development). Ways in which these activities affect flow are shown in Table 1. All activities that increase peak flow and decrease dry season flow change the timing of flow by decreasing the lag between rainfall and runoff.

Studies examining the potential effects of such changes fall into several types:

(1) laboratory studies relating growth rates and mortalities of specific organisms to salinity and temperature;

(2) field studies determining the frequencies and abundances of certain organisms at various salinities and temperatures;

(3) statistical studies determining estuarine food chains;

(4) statistical studies of the relationships between landings and prior salinities or river discharge rates (effects on recruitment).

Findings of these and related studies are summarized as follows:

(1) Salinity-occurrence ranges, tolerance ranges, and optima have been determined for a number of estuarine species.

(2) Certain synergistic effects of salinity and temperature have been established.

(3) Many organisms occurring in estuaries can withstand wide fluctuations in salinity. High calcium concentrations improve the capability of estuarine organisms to tolerate near-freshwater conditions.

(4) Estuaries are nursery grounds of many fish and invertebrate species that primarily occur, spawn, and are harvested offshore.

(5) Salinity gradients partition estuarine habitat between different species and (possibly) different cohorts of the same species.

(6) Low salinities (and possibly high salinities) reduce predation and parasitism on American oysters. Although difficult to demonstrate, juvenile fishes and invertebrates may be protected from predation by salinity extremes.

(7) Terrestrial detritus flushed into estuaries by the flow of fresh water forms the base of a major estuarine food chain.

(8) Significant relationships between fishery yields and freshwater flow have been demonstrated by correlation-regression techniques for a number of estuaries and species. The correlations have been positive in some estuaries and negative in others and have been positive for some species while negative for others.

Table 1. Effects of anthropogenic activities on the quantity of freshwater flow to estuaries.

		Increase peak flow	Decrease dry season flow	Increase total flow	Decrease peak flow	Increase dry season flow	Decrease total flow	Permanent effect	Temporary effect
1.	Dams		X[a]		X	X[a]		X	
2.	Diversions			X		X		X	
3.	Canals in uplands	X	X	X				X	
4.	Drainage ditches in wetlands	X	X	X				X	
5.	Deforestation	X	X	X				X	
6.	Clearcutting	X	X	X					X
7.	Road Construction	X	X	X				X	
8.	Paving	X	X	X				X	

[a] An effect of dams may be either of these

Gunter and his associates (Gunter 1945; Gunter et al. 1964) conducted early and extensive field studies establishing the range of salinity occurrences of fish and invertebrates on the gulf coast. Laboratory studies determining salinity tolerance ranges and optima and temperature-salinity interactions for shrimp species have been summarized by Zein-Eldin and Griffith (1969) and Venkataramiah et al. (1974). Pearse and Gunter (1957) showed that an ability to tolerate salinity extremes through one mechanism or another is an important characteristic of estuarine organisms. They reported on early indications that tolerance to low salinities is enhanced by high concentrations of calcium in the water.

The use of estuaries as nursery grounds was established by Gunter (1945) and supported by Sykes and Finucane (1966), Tabb et al. (1962), and many others. Gunter et al. (1964) described the partitioning of estuarine habitat among shrimp species by salinity gradients. Gunter (1945) was the first of many researchers to point out that the spatial distribution of organisms of different sizes within species appears to follow the salinity gradient in estuaries, with the smallest individuals in the lowest-salinity areas. Reid and Hoese (1958) demonstrated that factors other than salinity may be responsible for the observed distribution by size.

Ray (1954), Carriker (1955), Mackin (1956), Galtsoff (1964), Menzel et al. (1966), and Van Sickle et al. (1976) discussed the effect of lowered salinities on the enemies of oysters. Gunter (1961) proposed that mobile juvenile estuarine organisms, like oysters, are protected from stenohaline predators by estuarine salinity gradients.

Heald (1971) showed that large quantities of organic material derived from coastal swamp lands are flushed into estuaries of Everglades National Park, Florida. The importance of this material in estuarine food chains was determined by Odum (1971).

Strong positive correlations have been demonstrated between white shrimp landings and annual rainfall in Texas (Hildebrand and Gunter 1952; Gunter and Hildebrand 1954). Chapman (1966) showed that, during a seven-year period, average annual commercial fishery harvests per unit area in Texas estuaries were positively related to average gauged freshwater inflows in all but one estuary, the Mission-Aransas. Results of recent Gulf of Mexico studies utilizing correlation-regression analyses will be discussed in the next section.

RECENT RESEARCH IN GULF OF MEXICO ESTUARIES

Diverse estuarine systems found along the gulf coast from Florida to Texas have similar problems as a result of changes in the quantity and seasonal patterns of the freshwater flow they receive. A brief description will be given of estuaries in Florida, Louisiana, and Texas where current research related to these problems is being conducted.

SOUTH FLORIDA

Four characteristics of south Florida's rainfall pattern that influence the pattern of runoff to estuaries are: (1) moderately high annual volume; (2) annual variation; (3) seasonally variable distribution; and (4) spatial variation. Average annual rainfall varied from a low of 1,090 mm at Ortona Lock, west of Lake Okeechobee, to a high of 1,691 mm in South Miami (Thomas 1970), on the eastern coastal ridge, from 1960 through 1969. In a typical year approximately 75 percent of the rainfall occurs from May through October. In wet years more than 2,500 mm have been received at some stations; whereas in other years some stations have received less than 1,000 mm.

The high natural storage capacity of south Florida dampens the effect of rainfall variation on runoff to estuaries. Under natural conditions, there can be a lag of several months between peak rainfall and peak discharge, because runoff does not commence until certain storage threshholds are reached. This damping effect reduces wet season runoff and increases dry season runoff. Storage of water on the land in shallow sheets results in high evapotranspiration, particularly during the wet summer months, which reduces the total quantity of runoff. These relationships are described by the mass balance equation of classical hydrology:

Runoff = Rainfall - Evapotranspiration ± "Changes in Storage"

A main effect of the water management system in south Florida has been to reduce storage capacity. Removal of emergent vegetation, drainage of peat soils, and paving of land in urban areas of south Florida also have reduced the natural storage capacity. Increasing wet season discharge and decreasing dry season discharge to the estuaries have resulted, causing negative impacts on estuarine life (Browder 1977). Probably all south Florida estuaries have been affected. In addition, some estuaries have had the area of their watershed increased or decreased, accentuating the disruption of the natural runoff pattern.

Everglades National Park Estuaries

The subtropical estuaries of Everglades National Park, which cover approximately 1,295 km^2, are the nursery grounds for the pink shrimp of the Dry Tortugas fishery. They also provide nursery habitat for many commercially and recreationally important fish species. The watersheds of most of these estuaries have been greatly reduced by water management activities. The South Florida Water Management District schedules releases of water to the park in an attempt to compensate for discharge losses.

The freshwater flows of two distinct drainage systems have been modified. One is the Shark Slough system, which once received water from the Kissimmee-Okeechobee-Everglades drainage basin but now is limited to the Shark Slough area inside the park. The natural watershed was approximately 22,500 km^2. The present drainage area is approximately 2,059 km^2, or one-tenth its previous size. Receiving basins for this system are Whitewater Bay, a semi-enclosed estuary of 219 km^2 and a more open estuary of 324 km^2 at the mouths of the Broad, Harney and Shark Rivers. The park staff estimated that rainfall and releases to this system in a recent year amounted to 3.45 billion cubic meters.

The other system is northern Florida Bay, fringed by small embayments on its landward sides and a submerged sill on its seaward side that retards exchange with marine waters. This area of 546 km^2 historically received drainage from Taylor Slough and the southeastern coastal plain and probably had a contributing area of around 33 km^2, little of which now drains to northern Florida Bay and its embayments.

Periodicities of water deliveries to the park are thought to differ somewhat from that of the natural systems, and the total quantity delivered to the park's estuaries may be lower than under natural conditions. Salinities in Whitewater Bay are considerably higher now than they were historically (Davis 1980), although just how much higher is difficult to say because of the highly variable supra-annual rainfall pattern. Northern Florida Bay and its embayments often are hypersaline. The frequency and severity of hypersaline conditions are thought to have increased, but the changes have not been documented.

A general decline in fishery harvests in the park has been observed in recent years (Everglades National Park 1979). Davis (1980) found three significant changes have occurred in the park fisheries in the past 20 years : (1) a shift in age structure in red drum and spotted seatrout toward larger, more mature individuals; (2) consistent trends in catch rates (upward for red drum and downward for spotted seatrout); and (3) marked reductions in year-to-year variability of catch rates for both species. His preliminary analysis suggests that changes in environmental conditions related to freshwater inflow caused the changes in fishery stocks and the nature of the harvest.

Gordon River-Naples Bay Estuary

The Gordon River-Naples Bay estuary in Collier County on the southwest coast of Florida is an estuary that has had its watershed greatly increased by water-management alterations. Formerly three small creeks with a combined watershed area of 26 km^2 emptied into this small elongated water body of 5.26 km^2. The construction of the Golden Gate Canal system has increased the effective watershed of this estuary to 260 km^2, ten times the original size. Average maximum monthly discharge, which was approximately 2 m^3/s under natural conditions, has increased to approximately 44 m^3/s, approximately 20 times the predevelopment quantity. Although this estuary, by itself, is too small to greatly affect the fish production of the area, it is one of a multitude of smaller estuaries that makes a general contribution. It is mentioned in this report mainly because its problems are representative of those in other areas and the approach made to evaluation and solution of these problems is both unique and worthy of wider application.

Studies by the Collier County Conservancy determined the effect of the increased discharge on the hydrodynamics of the estuary and evaluated the impact on estuarine water quality and aquatic life. Van de Kreeke (1979) found highly stratified conditions in most of the estuary, including a connected system of deadend canals, throughout the summer and fall months, the period of high discharges. The stratification, fresh water overlying salt water, inhibited both vertical and horizontal mixing.

Hicks (1979a) found that the lack of mixing caused low levels of dissolved oxygen in bottom waters, particularly in the dead-end canals. Average dissolved oxygen values in August were below the state water quality standard of 4 mg/l in the canals and only slightly above the state standard in the bay.

Yokel (1979) found that benthic life was severly limited by the low dissolved oxygen levels, prevalent throughout summer and fall. Although pelagic fishes apparently were not adversely affected by the stratification, they were excluded from large areas of the Gordon River by extremely low salinities during several months. Planktonic organisms in the lower bay were washed out of the estuary by the high discharges, which may have negatively affected planktivorous fishes (Yokel 1979).

Reduced mixing caused by the high volume of freshwater discharge inhibited aquatic life in the estuarine system and lowered water quality to levels potentially hazardous to public health in the dead-end canals, which tended to trap and concentrate organic materials, including pathogenic bacteria (Hicks 1979b). A residential development is associated with the dead-end canals.

According to van de Kreeke (1979), water circulation in the dead-end canals would be substantially increased if freshwater discharge were reduced to an order of magnitude of 1 m^3/s. His calculations indicate that this rate would drive the circulation of water in the bay and canals. In Gulf of Mexico estuaries, where tidal amplitudes are low, density currents can be a greater mixing force than tides.

The Big Cypress Basin Board, which now has management jurisdiction over the watershed affecting the Gordon River-Naples Bay estuary, is planning to redesign the water management system to reduce wet season discharge to the estuary and, at the same time, alleviate other problems that have been caused by disruption of natural drainage patterns. In effect, what the board intends to do is utilize the many drained or partially-drained wetlands in the watershed for water storage and recharge areas (Simpson 1979). Holding the water on the land will have two beneficial effects on water delivery to the bay. (1) Because of increased evapotranspiration there will be a decrease in the total quantity of water going to the bay. (2) Because of increased infiltration into the substrate there will be an increase in the ratio of delayed runoff to immediate runoff, which will reduce peak flows and increase base flows, making the seasonal variation in water flow to the bay less pronounced. The board will try to create density currents in the bay to optimize mixing of bay and canal waters throughout the year.

The new design will also raise the dry-season water table, reduce forest fires, prevent saltwater intrusion, increase the availability of irrigation water for agricultural crops, and increase the productivity of wetlands and their ability to support wildlife. By utilizing wetland systems for water storage and recharge, the board will restore their natural function.

APALACHICOLA BAY SYSTEM

The Apalachicola Bay system is one of the most productive estuaries in Florida and contributes substantially to the economy of Franklin County. It supports a recreational fishing industry and a commercial fishery for oysters, shrimp, blue crabs, and several fish species. The oyster industry alone is responsible for 50 percent of county income (Boynton et al. 1977).

The Apalachicola estuary is a shallow, bar-built system of 549 km^2, which receives freshwater runoff from a 7,530 km^2 watershed in Florida, Georgia, and Alabama. Average depth of the estuarine system at mean low tide is 2.7 m. The usual tidal range is 0.5 to 0.7 m. The Apalachicola River, with an average flow rate of 540.7 m^3/s, provides the major input. Local runoff from 1,295 km^2 of swamp land also influences the estuary (Livingston et al. 1974).

Apalachicola River flow exhibits a long-term cycle, irregular in amplitude and duration, of approximately 5 to 7 years. The cycle is more a function of upriver (Georgia) rainfall than of local (Florida) rainfall (Meeter et al. 1979). River flow varies seasonally usually peaking sometime from January to April, with minimal flows during late summer and fall months. The seasonal cycle, like the long-term cycle, is more a function of upriver rainfall than local rainfall (Livingston et al. 1974).

This bay is characterized by low light penetration, considerable oyster bar development, and low primary productivity from benthic macrophytes (Livingston et al. 1978). Although Livingston et al. (1978) reported that there usually is little vertical or horizontal variation in temperature, this bay does stratify, and tongues of high-salinity water often extend into the bay along the bottom through passes (Livingston et al. 1974).

Peak levels of biological activity in this estuary appear to be related to hydrologic events (Sheridan and Livingston 1979). A seasonal succession of dominant fish and invertebrate species in the bay seems keyed to the seasonal river-flow pattern (Livingston 1976). Maximum influxes of dissolved organics, inorganic nutrients, and detritus are associated with periods of peak rivver discharge. The numbers of benthic infaunal organisms, and the demersal fishes and invertebrates that feed upon them, also peak at this time (Sheridan and Livingston 1979). Variations in abundance of different trophic groups appear roughly related to annual fluctuation in river discharge. For instance, Atlantic croaker and spot, benthic-feeding fish, reach maximum abundances in years of high river flow (Livingston et al. 1978).

Annual commercial oyster harvests were negatively correlated with annual river flow and annual blue crab harvests were positively correlated with annual river flow from 1957 through 1977 (Meeter et al. 1979). A strong negative correlation existed between oyster and blue crab landings. Meeter et al. (1979) thought this might indicate an influence on landings of unidentified economic factors such as catch effort, catch price, and fishing preference. A predator-prey relationship between blue crabs and oysters is another potential reason for the high negative correlation, since blue crabs are known to prey on oysters (Menzel et al. 1966). The results of Meeter and associates appear counter to the observation of Menzel and associates that oyster mortalities at given locations in Apalachicola Bay rise as salinity rises following dry weather conditions. Boynton (1975) proposed that salinity fluctuations rather than some optimum salinity provide the most favorable conditions for oysters. The study by Menzel et al. (1966) indicates that there are oyster enemies at both ends of the salinity spectrum, blue crabs being one example of an oyster predator that is favored by low salinities. Fluctuating salinity should inhibit predation/parasitism on oysters from both directions.

Apalachicola Bay is an example of an estuary receiving runoff from a dammed river. Cattle ranching and forest management activities, such as clearcutting, ditching, diking, and road construction also have affected freshwater inputs. Studies have been made of the long-term and short-term dynamics of chemical and biological factors in the bay and the effects of watershed alterations. Using spectral analysis, Meeter et al. (1979) determined that damming the upriver systems has thus far not substantially altered long-term river flow patterns but has affected short-term flow patterns, particularly during periods of low flow. Storage behind the dam is small relative to the flow of the river, and therefore the dam has had little impact on the pattern of flow (Boynton 1975).

Lowered water quality has resulted from the cattle and forestry operations. Effects of the forestry operations in Tate's Hell Swamp are particularly well documented (Livingston and Duncan 1979). Each aspect of the operations tended to increase the rate of response of local runoff to rainfall, which increased the amplitude and decreased the duration of runoff events, causing more abrupt than normal changes in salinity and nutrients in the vicinity of the swamp drainage. Sudden increases in water color and decreases in both dissolved oxygen and pH in upper portions of the bay were associated with periods of high runoff from the altered swamp. These periods coincided with periods when the upper bay ordinarily is heavily utilized as a nursery ground by fish and invertebrates. Reduced water quality from runoff from clearcut areas significantly reduced the number and biomass of white shrimp, the dominant invertebrate, in upper portions of the bay. Dissolved oxygen and pH levels increased in clearcut areas of the swamp after regrowth of a covering vegetation, suggesting that swamp vegetation has an ameliorating effect on these water-quality factors (Livingston and Duncan 1979).

MISSISSIPPI RIVER

Referred to as "the fertile crescent" (Gunter 1963), the coastal area dominated by the effluent of the Mississsippi River is one of the most productive fishery systems in the world. The three-state coastal area of Louisiana, Mississippi, and Alabama, with less than 4 percent of the Nation's coastline, produced almost 35 percent of U.S. marine coastal landings in 1978 (National Marine Fisheries Service 1979). Most of the estuarine area associated with the Mississippi River lies in the State of Louisiana, where extensive studies relating fishery production to freshwater flow have been conducted by the Louisiana Department of Wildlife and Fisheries.

Louisiana Estuaries

The total Mississippi drainage area covers 3.2 million square kilometers and includes one-eighth of North America. The Mississippi River and its main distributary, the Atchafalaya River, deliver an annual average of 17,400 m^3/s of fresh water to the estuarine zone of Louisiana, an area of approximately 13,866 km^2 (Barrett and Gillespie 1973).

Within this estuarine system, the salinity of upper bays is affected primarily by local rainfall, which averages 1,473 mm annually, peaking in July, August, and September, with a low in March and April. The influence of Mississippi-Atchafalaya flows on salinity predominates in the outer bays and nearshore open shelf area. River flow, a function of rainfall and snowmelt over the entire watershed, reaches maximum levels during April, May, and June and minimum levels during October, November, and December. The Mississippi-Atchafalaya discharges are responsible for 90 percent of the freshwater inflow in the Louisiana coastal system (Barrett and Gillespie 1973). Mississippi River discharge is a major contributor of land-derived organic compounds and nutrients such as nitrogen, phosphorus, and silica to Louisiana coastal waters (Ho and Barrett 1977).

According to Barrett and Gillespie (1973), shrimp recruitment is sensitive to salinity and is strongly influenced by the combination of localrainfall and river discharge. From 1967 to 1972, brown shrimp yields were greatest during years with minimal spring river discharges and rainfall. White shrimp yields were greatest during years with minimal summer river discharges and rainfall. Good years for brown shrimp and white shrimp generally coincided. Barrett and Gillespie (1973) suggested that excessive spring and summer river discharges and rainfall may lower estuarine and nearshore salinities below the tolerance limits of penaeid shrimp and substantially limit optimum nursery areas. This conclusion is supported by their observation that the area of inshore surface water utilized each year as fishing grounds varies from 8,000 km^2 to 11,500 km^2, depending upon the salinity regime. Maximum acreage is utilized during years of minimal river flow and local rainfall; whereas minimal acreage is utilized during years of high river flow and local rainfall. Barrett and Ralph (1976) suggested a relationship between annual brown shrimp catches and the number of acres of Louisiana estuarine surface waters above 10 ppt salinity during the spring. The most successful brown shrimp catches occur when the number of square kilometers above 10 ppt salinity exceeds 6,000. Water temperatures also affect brown shrimp recruitment success, but only for a brief period in April (Barrett and Gillespie 1973).

A regression equation based on research by Barrett and associates is found in the Gulf of Mexico Shrimp Fishery Management Plan (Gulf of Mexico Fishery Management Council 1980). The equation relates brown shrimp landings to (1) average water temperature at Grande Terre, Louisiana, April 16 to 22 (positive relationship); (2) average Mississippi River discharge from March to May (negative relationship); and (3) fishing effort, as quantified by Griffin (1978) (positive relationship). The equation explains 88 percent of the variation in brown shrimp landings.

Van Sickle et al. (1976) examined oyster production in the estuaries of the Barataria basin as related to salinity levels. They found that optimal conditions for oyster production existed within a salinity band which moved upstream when salinities increased in the inner bays. They said the oyster industry could be destroyed if oyster habitat is pushed into upstream areas of urban and industrial pollution. The increasing salinities are attributed to land losses and changes in Mississippi River flow, both of which result from natural and manmade causes.

The band of optimum salinity conditions for oysters was found to be in the 10-15 ppt range in the area just east of the Mississippi River by Breithaupt and Dugas (1979), who say that oyster larvae are killed below 10 ppt, while the oyster drill, a major predator of oysters, is intolerant of salinities below 15 ppt. Lindall et al. (1972) consider the oyster to be a good indicator species for the determination of the optimum salinity range for Louisiana estuarine fisheries in general. Although Mississippi River flood waters, such as those of 1973, cause extensive oyster mortalities, oyster populations appear to thrive in years immediately following such a flood (Dugas and Perret 1976), perhaps because oysters can become reestablished more quickly than their parasites and predators.

The Mississippi River delivers 272 million metric tons of sediment annually to Louisiana's deltaic coastal area and is responsible for building and maintaining the coastal marshes (Gagliano and van Beek 1976), which are the most extensive per unit coastline in the United States. Flow diversions have diminished the river's marsh-building capability by depositing approximately 80 percent of the sediment load at the edge of the shelf, where it no longer contributes to building marshes. Natural processes such as subsidence and sea-level rise are causing a loss of intertidal land not counteracted by sedimentation. An average land-loss rate of 42.7 km^2/yr was calculated by Gagliano and van Beek (1970). Due to anthropogenic activities such as drainage and spoil disposal, loss of wetlands is even greater (Craig et al. 1979). Coastal wetlands are important to fishery productivity. On a world-wide basis, Turner (1977) has demonstrated a relationship between shrimp yield and area of intertidal vegetation, adjusted for latitude. Faller (1979) has shown that local shrimp production gives a good fit to a function of shoreline density (the ratio of marsh-water interface to area of water) in Louisiana, which is the leading state for commercial shrimp production. These findings suggest that sediment deposition by rivers may be a critical factor in estuarine fisheries production.

TEXAS

Texas has diverse estuarine conditions and related problems because of climatic variation. The upper Texas coast has high rainfall, while the south coast is semi-arid. Current and potential problems for many of the estuaries are associated with increasing municipal and industrial water consumption and with the diversion of fresh water from one watershed to another to supplement irrigation supplies, as periodically proposed in the various versions of a Texas water plan.

In this summary we use median annual freshwater flows gauged, ungauged, and return flows from 1941 to 1976 calculated by the Texas Department of Water Resources (1979a, b,c,d,e)[1] divided by the total volume of each estuarine system below mean low water (Diener 1975), as a rough index for comparing and contrasting these estuaries with respect to their freshwater inflows. Flow medians (rather than means) were used because they appear to more adequately depict central tendencies. Our discussion starts with the Sabine-Neches system at the humid Texas-Louisiana border and ends with the Laguna Madre system at the semiarid Texas-Mexico border.

Sabine-Neches

The Sabine-Neches estuary is small, comprising only 4 percent of Texas' estuarine area (at mean low water), but has large freshwater inflows. This estuary primarily supports five major fish and shellfish species: bay anchovy, gulf menhaden, Atlantic croaker, spot, and blue crab (White and Perret 1974; Wiersema and Mitchell 1973). Until the mid 1960's the Sabine-Neches estuary was a major white shrimp nursery and fishery area, with higher catches per unit area than any other Texas estuary. Since 1966, the shrimp fishery has become virtually non-existent while the blue crab fishery has increased (National Marine Fisheries Service 1962-1977a). This estuary now leads all others in Texas in blue crab catch per unit area.

Dams, which have decreased spring flows and increased summer flows from the Sabine and Neches Rivers, are the cause of the loss of harvestable shrimp stocks in Sabine Lake (White and Perret 1974). Due to higher summer demands for hydroelectric power for air conditioning, the operating schedule of the Toledo Bend Dam on the Sabine causes high winter river flows not used for irrigation to be impounded until mid-May, when release begins. As a result, near-freshwater conditions now exist from late May through the summer. Under natural conditions, discharge rates into Sabine Lake were high in the spring but decreased during the summer, causing salinities to increase during this time. The low summer salinities caused by the dam's operating schedule are not suitable for brown and white shrimp (White and Perret 1974). On the other hand, these very low salinity conditions apppear to be ideal for blue crabs (More 1969). We estimate that the ratio of median freshwater inflow to estuarine volume in this estuarine system is approximately 50. The Texas Water Resources Department (1979a) was not able to calculate the rate of freshwater inflow required for maintenance of current fishery harvests.

Trinity-San Jacinto (Galveston)

The Trinity-San Jacinto (Galveston) estuary has just over one-fourth of the total estuarine area in Texas and a total median annual freshwater inflow of 5.0 times the estuarine volume. It leads the other Texas estuaries in harvests of oysters, blue crabs, and white and brown shrimp (National Marine Fisheries Service 1962-1977a). This estuary provides over four-fifths of the oysters and one-third the blue crabs in the entire Texas landings and nearly half of the shrimp caught in the Texas bays. It provides a larger catch of oysters and shrimp per unit area than any other Texas estuary. The importance of the Trinity River, the predominant source of fresh water for this estuary, was underscored by Cooper and Copeland (1973), who reported on results of a simulation model of Trinity Bay that related water exchange and retention characteristics of the bay to biological activity. They stated, "Our data indicate that reduction of normal Trinity River flows or additions of industrial effluents, or both, would result in reduction of estuarine community respiration rates. These reductions, indicative of decreased organic consumption rates, would lead to less productivity in Trinity Bay. Since Trinity Bay (as a major part of the most valuable Texas estuarine system) is a major nursery ground and supports significant populations of valuable organisms, reduction in river flow or addition of additional effluents, or both, would have a significant negative impact on fisheries and tourism economies of the Texas coast" (Cooper and Copeland 1973: 234).

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[1] Preliminary Texas Department of Water Resources calculations for the Laguna Madre were provided in a personal communication from Gary Powell of the Texas Department of Water Resources.

Water from both the Trinity and San Jacinto Rivers is heavily utilized by metropolitan Houston. With the existing Livingston reservoir, utilization of Trinity River water is increasing. Usage will increase further with the completion of the Lake Wallisville and other reservoirs.

The Trinity-San Jacinto (Galveston) estuary receives most of the return flows from Houston metroplex. Maintenance of adequate quality of the return flows may become critical because they probably will continue to increase as a result of the explosive population growth in the area. If adequate quality is maintained, some of the adverse impacts of diversion of San Jacinto and lower Trinity River waters for use in Houston may be avoided. However, the ability of the ecosystem to assimilate a given quantity of pollutants is reduced with the reduction of freshwater. Detrital and sediment in-flows will probably be reduced as freshwater inflows are reduced.

A draft report on the Trinity-San Jacinto Estuary by the Texas Department of Water Resources (1979b) indicated that current fishery harvests in the estuary could be maintained, and even slightly increased, with only three-fourths of the current average (four-fifths of the median annual inflows. This prediction is based on a model of commercial catches of selected species in the estuary. The model considers only environmental factors, but catch also is determined by numerous non-environmental influences, such as price paid for the catch, cost of fuel, attractiveness of other fisheries, and fishing regulations. Such non-environmental factors would have less influence if catch-per-unit effort rather than total catch were predicted by the model.

Lavaca-Tres Palacio (Matagorda)

The Lavaca-Tres Palacios (Matagorda) estuary, constituting about a fifth of the estuarine area in Texas, has a total median annual freshwater inflow of just 1.6 times the estuarine volume per year. Even though this estuary has over 70 percent of the area of the Trinity-San Jacinto

Estuary, it produced only about half the average harvests of white shrimp, brown shrimp, and blue crab and less than a tenth of the oysters during 1962-76 (National Marine Fisheries Service 1962-1977a). The Colorado River, in the eastern arm of the estuary, provides 65 percent of the gauged flow to the estuary and is the principal source of fresh water. This quantity is only half of the Colorado River flow because the other half has discharged directly to the Gulf since 1936 when a man-made channel was cut through the Matagorda Peninsula. Some historical records (Moore 1907) suggest that a much greater oyster production occurred when the entire Colorado River flowed to the bay and there were few upstream diversions. Other presentations at this symposium will address efforts by numerous individuals, agencies, environmental organizations, and fisherman organizations to have the entire flow of the Colorado River directed once again into the estuary. This will provide more fresh water, nutrients, detritus, and sediments to support the estuary's productivity.

A recent draft report on this estuary by the Texas Department of Water Resources (1979c) indicated that approximately the present annual median flow would be needed to maintain current fishery harvests. In a study performed for the Corps of Engineers, van Beek and Gagliano (1980) concluded that two primary biological effects would result from rediversion of the Colorado River into Matagorda Bay: (1) increase in area of productive wetland and aquatic habitat, and (2) decrease in the average salinity coupled with periodic flushing with freshwater floods from the river. Rediversion should result in a major enhancement of fishery harvests because of these effects. The other major source of freshwater inflows is the Lavaca-Navidad river system, which drains into the upper reaches of Lavaca Bay. Inflows will be reduced when the Palmetto Bend reservoir on the Navidad is completed and its yield significantly utilized.

Guadalupe (San Antonio)

The Guadalupe (San Antonio) estuary represents 11 percent of the state's estuarine area, but provides a somewhat higher percent of Texas estuarine harvests of white shrimp, brown shrimp, and blue crabs (National Marine Fisheries Service 1962-1977b). Parker (1955:210) noted in 1953, "During low-salinity years the reefs were composed primarily of Crassostrea virginica" (the American oyster) and, "Penaeus setiferus, the commercial white shrimp, virtually disappeared from the bays with the increase in salinity" (from 1948-1953).

An extensive 33-month study by the Texas Parks and Wildlife Department concluded that an annual average inflow of 2.5 to 3.8 times estuarine volume would provide optimum conditions in this estuarine system for shellfish production, with emphasis on white shrimp. A commercial shellfish production above 1.5 million pounds possibly could be maintained with a minimum annual inflow of 2.0 times estuarine volume (Childress et al. 1975). A Texas Department of Water Resources study (1979d) estimated that annual flows comparable to the current annual median inflows (3.3 times estuarine volume) would be required to maintain the present annual bay fishery harvests, which include annual shellfish harvests of 2.2 million pounds. So far only parts of the upper reaches and some tributaries of the Guadalupe-San Antonio river systems have been impounded, but some major reservoirs have been proposed downstream.

Mission-Aransas And

Nueces (Corpus-Christi)

The Mission-Aransas and Nueces (Corpus-Christi) estuaries both have median total annual inflows of only half the volume of the estuary. These estuaries make up 17 percent of the estuarine area in Texas, and accounted for 20, 9, 7 and 0 percent of the estuarine harvests of brown shrimp, white shrimp, blue crabs, and oysters, respectively, from 1962 through 1977.

Parker (1955) noted years ago the adverse impacts of high salinity on white shrimp and oysters in the Mission-Aransas estuary. More recently, Chapman (1973:249) observed, "The diversion and consumptive use of tributary fresh water received by the southwestern Texas estuaries already has reached critical proportions. Tributary flow to Corpus Christi Bay, Texas, has been reduced to the point where the estuary now becomes hypersaline most summers through excessive evaporation, to the detriment of fishery resources." The Texas Department of Water Resources (1979e) predicted that the fisheries could be maintained, and even increased by over a fourth, with an amount just slightly greater than the historical median annual inflows. However, Copeland (1966:1836) noted that, in these bays "The minimum freshwater contribution required to maintain the present commercial fisheries is not reached in some years." A major reservoir, Choke Canyon, now under construction in the principal drainage basin, the Nueces, will increase the frequency of insufficient inflows when its yield begins to be utilized.

Laguna Madre

The Laguna Madre, the southernmost estuarine system, has a median total annual inflow of only 0.4 times the estuarine volume (0.2 in the upper and 0.5 in the lower Laguna Madre; and shrimp fishing, except for bait, is not permitted. Sciaenid fish, which are fished both commercially and recreationally, are abundant in the upper Laguna Madre (Simmons 1957), Baffin and Alazan Bays, and the lower Laguna Madre (Breuer 1957; 1962). Stokes (1974) found that postlarval and juvenile brown shrimp were abundant in over 40 percent of the lower Laguna Madre, whereas white shrimp were abundant in less that 5 percent of the estuary. This part of the estuary primarily was where freshwater flows, or return flows, enter.

Harvests of brown shrimp in Texas estuaries represent only approximately 5 percent by weight of brown shrimp catches along the Texas coast (National Marine Fisheries Service 1962-1977b); therefore, the bay catches referred to above may be poor indicators even of relative population. Correlation-regression analyses indicated that offshore shrimp harvests for all three species, white, brown, and pink, are positively correlated with spring (April-June) inflow and negatively correlated with winter (January-March) and summer (July-August) inflows. Brown and pink shrimp harvests are negatively correlated with fall (September-October) harvests. These analyses corroborate the Sabine Lake finding by White and Perret (1974) that the seasonality of discharges as well as total annual quantities have an important influence on recruitment of shrimp.

CONCEPTUAL MODEL

The flow of fresh water into estuaries may influence fishery production, either directly or indirectly, in at least five ways: (1) transport of nutrients; (2) transport of detritus; (3) transport and deposition of sediments; (4) reduction of salinity; and (5) mixing and transport of water masses. The pathways by which fresh water may influence fishery production are shown in the simple energy-flow model in Figure 1. The model is a conceptual integration of a set of hypotheses supported in part by the material presented previously.

In the model, direct river inputs are sediments, nutrients, and fresh water. Sediments build and maintain tidal wetlands (marsh), counteracting both natural and anthropogenic processes that destroy tidal wetlands. Nutrients in river water stimulate productivity of wetland vegetation. The physical force of runoff flushes decaying wetland vegetation into tidal creeks and open waters, where it is processed by microorganisms into food for benthic animals, which are fed on by juvenile fish and invertebrates. Nutrients released to open water stimulate productivity of phytoplankton and seagrasses, which also provide food for juvenile fish and shellfish, either directly or through the grazing or detrital chains.

Freshwater inputs establish chemical potential energy that sometimes drives the mixing of the estuary. The relationship between freshwater inputs and mixing is a complex function that is dependent on tidal amplitude (both astronomical and wind-driven) and the area and geomorphology of the estuary (Hansen and Rattray 1966). Simmons (1955) suggested the ratio of freshwater flow over one tidal cycle to tidal prism (tidal amplitude multiplied by estuarine area) as a rough index of type of mixing in coastal plain estuaries. Ratios in the range of 1:1 indicated stratified conditions. This means poor vertical mixing, with bottom waters that are usually low in oxygen. Ratios on the order of 1:10 suggest a partially-mixed estuary. The moderate vertical salinity gradients in partially-mixed estuaries can be a more important force than tides in driving estuarine circulation in regions where tidal amplitudes are low. Ratios approaching 1:100 indicate a vertically homogeneous estuary with no salinity differences between surface and bottom. Although well-mixed vertically, this type of estuary may be less well-mixed horizontally than the partially-mixed estuary because of the lack of the vertical salinity gradient necessary to drive density currents. The mixing characteristics of an estuary may vary seasonally if seasonal variation in freshwater inputs is large. The mixing ratio should be used only as a rough guide because it does not consider estuarine geomorphology, an important determinant of mixing type.

Three pathways shown in Figure 1 are dependent on mixing characteristics. Mixing characteristics determine the availability of oxygen to bottom waters, which in turn determines the rate of decomposition

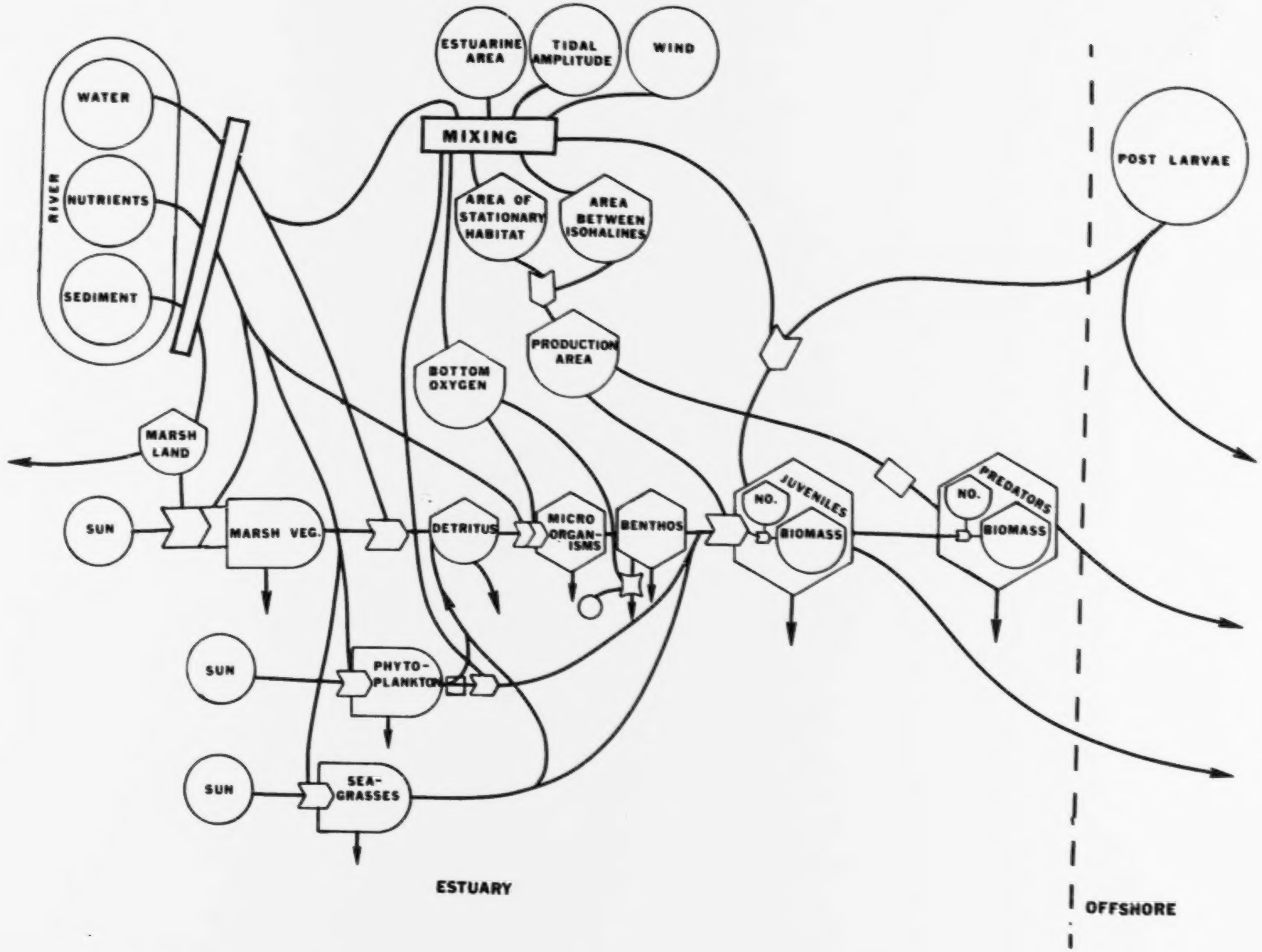
ESTUARINE AREA
TIDAL AMPLITUDE
WIND
WATER
RIVER
NUTRIENTS
SEDIMENT
MIXING
AREA OF STATIONARY HABITAT
AREA BETWEEN ISOHALINES
POST LARVAE
PRODUCTION AREA
BOTTOM OXYGEN
MARSH LAND
SUN
MARSH VEG.
DETRITUS
MICRO ORGANISMS
BENTHOS
NO.
JUVENILES
BIOMASS
NO.
PREDATORS
BIOMASS
SUN
PHYTO-PLANKTON
SUN
SEA-GRASSES
ESTUARY
OFFSHORE

Figure 1. Energy-flow diagram (Odum and Odum 1976) showing pathways of potential effects of river inflows on production of fishery stocks.

of detritus by microorganisms. Rate of decomposition rather than quantity of detritus determines the rate of detritus utilization by benthic organisms (Tenore and Hanson 1980).

The river in its interaction with the tides determines the "slope" of the salinity gradient and, therefore, the area of water within the favorable salinity range for a given species. Steeper slopes mean smaller areas between isohalines; gradual slopes means broad areas between isohalines. River flow also positions the area of favorable salinites relative to important stationary habitat factors such as shoreline, water depth, and bottom type. The size of the area of overlap of these factors, integrated over the nursery season, as well as food concentration, may determine the survival and growth rates of juvenile organisms.

Freshwater inputs, through effect on mixing, also may influence recruitment of harvestable fish and shellfish by affecting currents that transport estuarine-dependent postlarvae into estuaries from offshore spawning areas. Shoreward-moving bottom currents caused by stratification and surface currents (and sometimes also bottom currents) caused by density gradients may be a major mechanism for transport of postlarvae into estuaries. Although some evidence for postlarval transport by bottom currents exists (Wallace 1940), postlarval transport by wind (ekman transport) and tides is better documented.

IMPLICATIONS OF THE MODEL

A wide body of literature supports the relationship between nutrient inputs and fishery production indicated in the model. This relationship probably is not simple because high nutrient inputs sometimes can cause a shift in taxonomic composition toward algal species that, for one reason or another, are not valuable in the food chain. On the other hand, there probably is a nutrient concentration so low that no useful energy can be obtained by animals from phytoplankton. Nevertheless, strong linear correlations between freshwater flow, nutrients, and fishery production have been found (Sutcliffe 1972; 1973).

The importance of detritus inputs to fishery production also is well documented. The effect on detritus utilization of seasonally or permanently low oxygen in bottom waters due to stratification has not been discussed. Detritus is not always utilized immediately after it arrives in an estuary. Delays of a season or longer between deposition and utilization may occur. Detrital inputs to areas of permanently low oxygen may have little influence on the production of anything other than fossil fuels.

There are at least three reasons why production of fishery species may correlate with area of favorable habitat: (1) growth may be related to the total quality of available food, and total quantity of available food is the product of food concentration and area; (2) survival and growth rates probably are negatively density dependent; therefore the larger the favorable area, the higher the survival and growth rates within it; and (3) the smaller the area of favorable habitat, the greater the percentage of juvenile animals found in poor habitat, where lower survival and growth rates would be expected.

Variance from seawater concentration, rather than low salinities per se, may provide favorable habitat for the euryhaline young of many species that utilize estuaries as nursery grounds. The whole idea of recruitment being correlated with area of favorable habitat is entirely consistent with Gunter's hypothesis (Gunter 1961) that euryhaline young are protected from stenohaline predators by salinity gradients in estuaries.

The simple input-output model in Figure 2 depicts freshwater flow as the input that determines area of favorable habitat, which in turn determines the output, fishery recruitment. Factors such as temperatures during critical periods, freezes, and hurricanes also affect recruitment, creating "noise" in the relationship between area and recruitment. Barring substantial interference from "noise", production of fish and shellfish recruits in estuaries may correlate with area of favorable habitat during the nursery season, although not necessarily with freshwater flow during this time. Because area of favorable habitat is a function of complex interactions between freshwater flow, tidal prism, and estuarine geomorphology, the relationship between fishery production and freshwater flow is not likely to be linear over more than a restricted range, differing for each estuary and each species. For any estuary there is a rate of freshwater flow that will push the band of favorable salinities beyond estuarine boundaries into open waters, eliminating favorable habitat entirely. Likewise, for every estuary there is a freshwater flow so low that the band of favorable salinities retreats upriver where the area of favorable habitat is small.

A complication is that factors other than freshwater flow could change the area of favorable habitat. Seasonal and supra-annual variation in tidal stages can vary the area covered by water. For instance, Allen et al. (1980) observed that the greatest area of tideland in the Florida Bay region is flooded by an annual rise in sea level that occurs from August to December. They further noted that the annual peak in abundance of juvenile pink shrimp occurs at that time. They quote Collier and Hedgepeth (1950) as saying, "Some of the principal fisheries are dependent upon the young gaining the protection and nourishment offered by tidal flats during the early days of their lives. The degree to which a given year-class is successful might depend upon the extent, both spatial and temporal, to which the tidal flats and low marshlands are flooded." Allen et al. (1980) suggest that cyclic variations in height of Florida sea level may have a marked influence on the annual abundance of juvenile pink shrimp and, ultimately, the offshore commercial shrimp catch.

Most fishery biologists conducting research in estuaries seem to be unaware of the nonlinear effects of freshwater flow on mixing or the potential importance of mixing conditions to the survival and growth of juvenile and sessile estuarine species. On the other hand, although ocean engineers and physical oceanographers study currents and mixing patterns in estuaries, they seem unaware of the questions that need to be answered to relate fishery recruitment to freshwater flow rates. An inter-disciplinary effort is the best way to insure that a quantitive understanding of the relationship between freshwater flow and fishery production is developed.

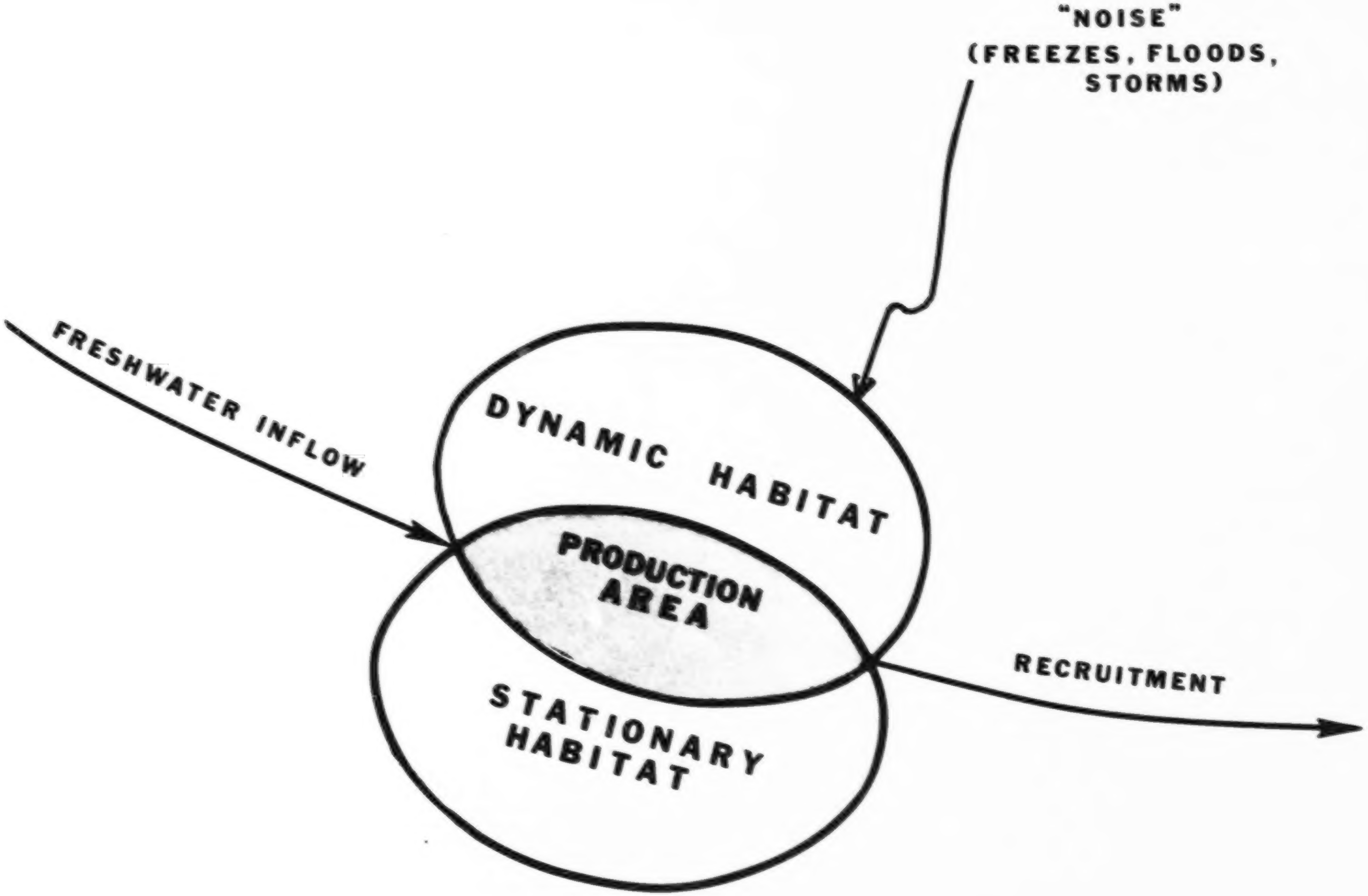
"NOISE"
(FREEZES, FLOODS, STORMS)
FRESHWATER INFLOW
DYNAMIC HABITAT
PRODUCTION AREA
STATIONARY HABITAT
RECRUITMENT

Figure 2. Simple input-output model diagram suggesting relationship of freshwater inflow to fisheries production through its effect on area of favorable estuarine nursery habitat.

Such a study should have five data-gathering elements: (1) monitoring of freshwater flow rates; (2) measurement of vertical profiles of salinity, temperature, oxygen, and current direction and velocities; (3) measurement of detrital biomass and decomposition rates; (4) mapping of isohalines and quantification of area between isohalines periodically during the nursery season; (5) mapping and quantification of potentially productive habitat area, based on physical and biological features, at different levels of high tide; and (6) monitoring of fishery yield and effort. In addition, we should also measure the input rates of nutrients, detritus, sediments, and toxic compounds.

Some of the potential relationships that should be explored through statistical analysis and computer modeling are: (1) "Production area" (defined as the area of overlap of the favorable salinity band and favorable stationary physical and biological habitat features) vs. freshwater flow during the nursery season; (2) stratification vs. freshwater flow; (3) fishery production vs. production area; (4) fishery production vs. area of marsh; (5) detrital decomposition vs. stratification; (6) recruitment vs. currents during critical periods of postlarval transport; and (7) fishery production vs. water quality.

Such studies, conducted in a number of gulf coast estuaries and employing ocean engineers, physical oceanographers, remote sensing specialists, systems ecologists, hydrologists, geologists, and fishery biologists could contribute significantly to a quantitative understanding of the role of fresh water in fishery production.

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LITERATURE CITED

Allen, D. M.; Hudson, J.H.; Costello, T.J. Postlarval shrimp (Penaeus) in the Florida Keys: species, size, and seasonal abundance. Bull. Mar. Sci. 30:21-33; 1980.

Barrett, B. B.; Gillespie, M. S. Primary factors which influence commercial shrimp production in coastal Louisiana. La. Wildl. and Fish. Comm. Tech. Bull. 9; 1973.

Barrett, B.B.; Ralph, E.J. 1976 environmental conditions relative to shrimp production in coastal Louisiana. La. Wildl. and Fish. Comm. Tech. Bull. 21; 1976.

Boynton, W.R. Energy basis of a coastal region: Franklin County and Apalachicola Bay, Florida. Gainsville, FL: Univ. Fla; 1975. Dissertation.

Boynton, W.; Hawkins, D. E.; Gray, C. A modeling approach to regional planning in Franklin County and Apalachicola Bay, Florida. Hall C.A.A.; Day, J. W., Jr., eds. Ecological modeling in theory and practice. New York: Wiley; 1977: 477-506.

Breithaupt, R. L.; Dugas, R. J. A study of the southern oyster drill (Thais haemastoma) distribution and density on the oyster seed ground. La. Wildl. and Fish. Comm. Tech. Bull. 30; 1979.

Breuer, J. P. An ecological survey of Baffin and Alazan Bays, Texas. Publ. Inst. Mar. Sci. Univ. Tex. 4:134-155; 1957.

Breuer, J. P. An ecological survey of the lower Laguna Madre of Texas, 1953-1959. Publ. Inst. Mar. Sci. Univ. Tex. 8:153-183; 1962.

Browder, J. The estuary viewed as a dynamic system. Seaman, W., Jr.; McLean, R., eds. Seminar proceedings: freshwater and the Florida coast: southwest Florida; 1977 May 26-27; Tampa, FL. Brooksville, FL; Southwest Florida Management District; Gainesville, FL; Florida Sea Grant; 1977:144-170.

Carriker, M. R. Critical review of biology and control of oyster drills, Urosalpinx and Eupleura. U.S. Dept. Inter. Fish Wildl. Serv. Spec. Sci. Rep. Fish. 148:1-150; 1955.

Chapman, C. R. The Texas basins project. Smith, R. F.; Swartz, A. H.; Massman, W. H., eds. A symposium on the estuarine fisheries 1964 September, Atlantic City, NJ: Washington, DC: Am. Fish. Soc. Spec. Publ. 3: 1966; 83-92.

Chapman, C.R. The impact on estuaries and marshes of modifying tributary runoff. Charbreck, R. H. ed.; Proceedings coastal marsh estuary managment symposium, 1972 July, Baton Rouge, LA: Louisiana State University, 1973; 235-238.

Childress, R.; Bradley, E.; Hagen,E.; Williamson, S. The effects of freshwater inflows on hydrological and biological parameters in the San Antonio Bay system, Texas. Coastal Fisheries Branch. Tex. Parks Wildl. Dept.; 1975.

Collier, A.; Hedgpeth, J.W. An introduction to the hydrography of tidal waters of Texas. Publ. Inst. Mar. Sci. Univ. Texas 1:121-194; 1950.

Cooper, D. C.; Copeland, B. J. Responses of continuous-series estuarine microecosystems to point-source input variations. Ecol. Monogr. 43:213-236; 1973.

Copeland, B. J. Effects of decreased river flow on estuarine ecology. J. Water Pollut. Control Fed.: 1831-1839; 1966.

Craig, N.J.; Turner, R.E.; Day, J. W. Jr. Land loss in coastal Louisiana. Environ. Manage. 3:133-144; 1979.

Davis, G. E. Changes in the Everglades National Park red drum and spotted seatrout fisheries 1958-1978: fishing pressure, environmental stress or natural cycles? Williams, R. O.; Weaver, J. E.; Kalber, F.A. eds., Proceedings colloquia on biology and management of red drum and seatrout. Ocean Springs, MS: Gulf States Mar. Fish. Comm.; 1980; 81-87.

Diener, R.A. Cooperative Gulf of Mexico estuarine inventory and study - Texas: area description. NOAA Tech. Rept.; NMFS CIRC-393: 1975; 129p. Available from: D83, Technical Information Division, Environmental Science Information Center, NOAA, Washington, DC 29235.

Dugas, R.J.; Perret, W.S. The effects of 1973 spring floodwaters on oyster population in Louisiana. Rogers, W.A.; Wegener, W.; Williams, L.E., Jr., eds. Proceedings of the 29th Annual Conference, S.E. Assoc. Game Fish Comm.; 1975 October 12-15. 1976; 208-214.

Everglades National Park. Executive Summary: an assessment of fishery management options at Everglades National Park, Homestead, FL: U.S. Dept. Inter., Natl. Park Serv.; 1979: 61 p.

Faller, K. H. Shoreline as a controling factor in commercial shrimp production. NASA Tech. Mem.; TM-72-732. Bay St. Louis, MS: NASA Natl. Space Technol. Lab.; 1979; 27 p.

Gagliano, S.M.; van Beek, J.L. Geologic and geomorphic aspects of deltaic processes, Mississippi delta system. Baton Rouge, LA: Center for Wetland Resources, La. State Univ.; Hydrologic and Geologic Studies of Coastal Louisiana 1; 1970: 103-125.

Gagliano, S.M.; van Beek, J.L. Mississippi River sediment as a resource. Safena, R. S., ed. Modern Mississippi delta-depositional environments and processes. Guidebook for Annual AAPG/SEPM Convention. New Orleans, LA: May 1976: 103-125. available from: Coastal Environments, Inc. 1260 Main Street, Baton Rouge, LA 70892.

Galtsoff, P. S. The American oyster, Crassostrea virginica (Gmelin). U.S. Dept.Inter. Fish and Wildl. Serv., Fish. Bull. 64; 1964.

Griffin, W. L. Estimation of relative fishing power from interviewed landings to total landings. Unpublished manuscript; 1978. Located at: Tex. A&M Univ., College Station.

Gulf of Mexico Fishery Management Council. Fishery management plan for the shrimp fishery of the Gulf of Mexico, United States waters, 1980. Available from Gulf of Mexico Fishery Management Council, Suite 881, 5401 W. Kennedy Blvd., Tampa, FL 33609.

Gunter, G. Studies on marine fishes of Texas. Publ. Inst. Mar. Sci. Univ. Tex. 1; 1945.

Gunter, G. Mortality of oysters and abundance of certain associates as related to salinity. Ecology 36: 601-605; 1955.

Gunter, G. Some relations of estuarine organisms to salinity. Limnol. Oceanogr. 6:182-190; 1961.

Gunter, G. The fertile fisheries crescent. J. Miss. Acad. Sci. 9:286-290; 1963.

Gunter, G.; Hildebrand, H.H. The relation of total rainfall of the State and catch of the marine shrimp (Penaeus setiferus) in Texas waters. Bull. Mar. Sci. Gulf Caribb. 4:95-103; 1954.

Gunter, G.; Christmas, J.Y.; Killegrew, R. Some relations of salinity to population distributions of motile estuarine organisms, with special reference to penaeid shrimp. Ecology 45:181-185; 1964.

Hansen, D. V.; Rattray, M., Jr. New dimensions in estuary classification. Limnol. Oceanog. 11:319-326; 1966.

Heald, E. J. The production of organic detritus in a south Florida estuary. 1971. Univ. Miami Sea Grant. Tech. Bull. No. 6. Available from: University of Miami Rosenstiel School of Marine and Atmospheric Science, 4600 Rickenbacker Causeway, Miami, FL 33149.

Hicks, D.B. Appendix D-Water quality. The Naples Bay study. Available from Collier County Conservancy. P.O. Box 2136, Naples, FL 33939. 1979a: 69 p.

Hicks, D. B. Appendix D-1 - Public health. The Naples Bay study. Available from Collier County Conservancy, P.O. Box 2136, Naples, FL 33939. 1979b: 15 p.

Hildebrand, H. H.; Gunter, G. Correlation of rainfall with the Texas catch of white shrimp, Penaeus setiferus (Linneaus). Trans. Am. Fish. Soc. 82:151-155; 1952.

Ho, C. L.; Barrett, B. B. Distribution of nutrients in Louisiana coastal waters influenced by the Mississippi River. Estuarine Coastal. Mar. Sci. 5:173-195; 1977.

Lindall, W.M., Jr.; Hall, J.R.; Sykes, J.E.; Arnold, E.L., Jr. Louisiana coastal zone: analyses of resources and resource development in connection with estuarine ecology. Sections 10 and 13, Fishery resources and their needs. Report of the commerical fishery work unit of the National Marine Fisheries Service to the U.S. Army Corps of Engineers (Contract #14-17-002-430); 1972; 320 p. Located at: NMFS, Southeast Regional Office, 9450 Koger Blvd., St. Petersburg, FL 33702.

Livingston, R.J. Diurnal and seasonal fluctuations of organisms in a north Florida estuary. Estuarine Coastal Mar. Sci. 4:373-400; 1976.

Livingston, R.J.; Iverson, R.L.; Estabrook, R.H.; Keys, V.E. Taylor, J., Jr. Major features of the Apalachicola Bay system: physiography, biota, and resource management. Fla. Sci.37: 245-270; 1974.

Livingston, R.J.; Thompson, N. P.; Meeter, D.A. Long-term variation of organochloride residues and assemblages of epibenthic organisms in a shallow north Florida (USA) estuary. Mar. Biol. 46:355-372; 1978.

Livingston, R. J.; Duncan, J. L. Climatological control of a north Florida coastal system and impact due to upland forestry management. Livingston, R.J., ed. Ecological processes in coastal and marine systems. New York: Plenum Press; 1979: 339-381.

Mackin, J. C. Dermocystidium marinum and salinity. Proceedings of National Shellfish Association 46; 1955 August. Washington, D.C.: U.S. Dept. Inter. Fish Wildl. Serv., 1956:116-128.

Meeter, D.A.; Livingston, R.J.; Woodsum, G.C. Long-term climatological cycles and population changes in a river-dominated estuarine system. Livingston, R. J., ed. Ecological processes in coastal and marine systems. New York: Plenum Press; 1979: 315-338.

Menzel, R.W.; Hulings, N.C.; Hathaway, R.R. Oyster abundance in Apalachicola Bay, Florida, in relation to biotic associations influenced by salinity and other factors. Gulf Res. Rep. 2:73-96; 1966.

Moore, H.F. Survey of oyster bottoms in Matagorda Bay, Texas. Bowers, G.M., Comm. Report of the Commissioner of Fisheries for the fiscal year 1905 and special papers. Washington, D.C.: Bur. of Fish. 1907. Doc. No. 610.

More, W.R. A contribution to the biology of the blue crab (Callinectes sapidus Rathbun) in Texas, with a description of the fishery. Tex. Parks Wildl. Dept. 1969. Tech. Ser. 1.

National Marine Fisheries Service, NOAA, U.S. Dept. Comm. Texas Landings. Annual Summaries. Current Fishery Statistics Nos. 3309, 3627, 3901, 4156, 4529, 4675, 4962, 5232, 5616, 5923, 6124, 6423, 6723, 7223, and 7523. Washington, D.C.: 1962-1977a.

National Marine Fisheries Service, NOAA, U.S. Dept. Comm. Gulf coast shrimp data. Annual Summaries. Current Fisheries Statistics Nos. 3358, 3515, 3784, 4111, 4411, 4781, 5107, 5412, 5712, 5925, 6126, 6425, 6725, 6925, 7225, and 7523. Washington, D.C.: 1962-1977b.

National Marine Fisheries Service, NOAA, U.S. Dept. Comm. Preliminary report. Fisheries of the United States, 1978. Current Fishery Statistics No. 7800. Washington, D.C.: 1979; 120p.

Odum, H.T.; Odum, E.C. Energy basis for man and nature. New York: McGraw-Hill; 1976.

Odum, W.E. Pathways of energy flow in a south Florida estuary. 1971. Univ. Miami Sea Grant Tech. Bull. No. 7; Available from: University of Miami, Rosenstiel School of Marine and and Atmospheric Science, 4600 Rickenbacker Causeway, Miami, Fl 33149.

Parker, R.H. Changes in the invertebrate fauna, apparently attributable to salinity changes, in the bays of central Texas. J. Paleont. 29:193-211; 1955.

Pearse, A.S.; Gunter, G. Salinity. Hedgpeth, J.W., ed. Treatise on marine ecology and paleoecology. Geol. Soc. Am. Mem. 67. Washington, D.C.: American Geological Society; 1957: 129-158.

Ray, S.M. Biological studies of Dermocystidium marinum, a fungus parasite of oysters. Monograph in biology. Rice Institute Pamphlet, Special Issue. Houston, TX: 1954; 114p.

Reid, G.K.; Hoese, H.D. Size distribution of fishes in a Texas estuary. Copeia 1958: 225-231.

Sheridan, P. F.; Livingston, R. J. Cyclic trophic relationships of fishes in an unpolluted river-dominated estuary in north Florida. Livingston, R. J., ed. Ecological processes in coastal and marine systems. New York: Plenum Press; 1979: 143-161.

Simmons, E.G. An ecological survey of the upper Laguna Madre of Texas. Publ. Inst. Mar. Sci. Univ. of Tex. 4:156-200; 1957.

Simmons, H. B. Some effects of upland discharge on estuarine hydraulics. Proceedings, American Society of Civil Engineers 81: Paper 792; 1955.

Simpson, B. Appendix F-Engineering. The Naples Bay study. 1979; 27 p. Available from Collier County Conservancy, P.O. Box 2136, Naples, FL 33939.

Stokes, G.M. The distribution and abundance of penaeid shrimp in the lower Laguna Madre of Texas, with a description of the live bait shrimp fishery . 1974; 32 p. Tex. Parks Wildl. Dept. Tech. Ser. 15.

Sutcliffe, W.H. Some relations of land drainage, nutrients, particulate material, and fish catch in two eastern Canadian bays. J. Fish. Res. Board. Can. 29: 357-362; 1972.

Sutcliffe, W.H. Correlations between seasonal river discharge and local landings of American lobster (*Homarus americanus*) and Atlantic halibut (*Hippoglossus hippoglossus*) in the Gulf of St. Lawrence. J. Fish. Res. Bd. Can. 30: 856-859; 1973.

Sykes, J.E.; Finucane, J.H. Occurrence in Tampa Bay, Florida, of immature species dominant in Gulf of Mexico commercial fisheries. U.S. Dept. Inter. Fish Wildl. Serv. 1966. Fish. Bull. 65: 369-379.

Tabb, D. B.; Dubrow, D. L.; Manning, R. B. The ecology of northern Florida Bay and adjacent estuaries 1962. Fla. St. Bd. Conserv. Tech. Serv. 37.

Tenore, K. R.; Hanson, R. B. Availability of detritus of different types and ages to a polychaete macroconsumer, *Capitella capitata*. Limnol. Oceanogr. 25:553-558; 1980.

Texas Department of Water Resources. Sabine-Neches estuary: a study of the influence of fresh water inflows. LP-116. 1979a Dec. Draft report. Available from: P.O. Box 13087, Capitol Station, Austin, TX 781711.

Texas Department of Water Resources. Trinity-San Jacinto estuary: a study of the influence of freshwater inflows. LP-113. 1979b Dec. Draft report. Available from P. O. Box 13087, Capitol Station, Austin, TX 78711.

Texas Department of Water Resources. Lavaca-Tres Palacios estuary; a study of the influence of freshwater inflows. LP-106. 1979c Sept. Draft report. Available from: P. O. Box 13087, Capitol Station, Asutin, TX 78711.

Texas Department of Water Resources. Guadalupe estuary: a study of the influence of freshwater inflows. LP-107. 1979d Oct. Draft report. Available from: P. O. Box 13087, Capitol Station, Austin, TX 78711.

Texas Department of Water Resources. Nueces and Mission-Aransas estuaries: a study of the influence of freshwater inflows. LP-107. 1979e Nov. Draft report. Available from: P. O. Box 13087, Capitol Station, Austin, TX 78711.

Texas Department of Water Resources. The influence of freshwater inflows upon the major bays and estuaries of the Texas gulf coast. LP-115. 1979f Dec. Executive Summary. Available from: P. O. Box 13087, Capitol Station, Austin, TX 78711.

Thomas, T.M. A detailed analysis of climatological and hydrological records of south Florida with reference to man's influence upon ecosystem evaluation. Univ. Miami, Tech. Rep. 70-2: 1970; 80 p. Available from: University of Miami Rosenstiel School of Marine Science, 4500 Rickenbacker Causeway, Miami, FL 33149.

Turner, R. E. Intertidal vegetation and commercial yields of penaeid shrimp. Trans. Am. Fish. Soc. 106:411-416; 1977.

van Beek, J. L., Gagliano, S. M., Delta-building potential of the Colorado River central Texas. Contrib. No. DACW-64-79-C-0024. Append. I - Delta growth study. Mouth of Colorado River, Texas. Draft Phase 1 General Design Memorandum and Environmental Impact Statement (Diversion Features); Galveston, TX: U.S. Army Engineer District; 1980.

van de Kreeke, J. Appendix C - Hydrography. The Naples Bay study 1979; 43 p. Available from Collier County Conservancy, P. O. Box 2136, Naples, FL 33939.

Van Sickle, V. R.; Barrett, B. B.; Ford, T.B.; Gulick, L.J. Barataria Basin: salinity changes and oyster distribution. Sea Grant Publ. No. LSU-T-76-002: 1976 22p. Available from: Center for Wetland Resources, Louisiana State University, Baton Rouge, LA.

Venkataramiah, A.; Lakshmi, G. J.; Gunter, G. Studies on the effects of salinity and temperature on the commercial shrimp, *Panaeus aztecus* Ives, with special regard to survival limits, growth, oxygen consumption and ionic regulation. Ocean Springs, MS: Gulf Coast Research Laboratory. Contract Rep. H-74-2: 1974. 134 p. Contract Report. Available from: U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Wallace, D.H. Sexual development of the croaker, *Micropogon undulatus*, and distribution of the early stages in the Chesapeake Bay. Trans. Am. Fish. Soc. 70: 474-482; 1940.

White, C.J.; Perret, W.S. Short term effects of the Toledo Bend Project on Sabine Lake, Louisiana. Mitchell, A.L., ed. Proceedings, 27th Annual Conference, S.E. Assoc. Game Fish Comm.; 1973 October 14-17. Hot Springs, AR: 1974; 710-721.

Wiersema, J.M.; Mitchell, R.P. A survey of the Sabine Lake hydrography as it relates to the commercial fishery. Sabine Power Sta. Ecol. Prog. Vol. 2. TRACOR Proj. No. 077-004-12; Doc. No. T73-AU-9506-U. 1973; 54. Available from: Espey, Huston & Associates, Inc., P. O. Box 519, Austin, TX 78767.

Yokel, B. Appendix E - Biology. The Naples Bay study 1979; 54p. Available from Collier County Conservancy, P.O. Box 2136, Naples, FL 33939.

Zein-Eldin, Z.P.; Griffith, G.W. An appraisal of the effects of salinity and temperature on growth and survival of postlarval penaeids. Mistakidas, M.N., ed. Proceedings on the world scientific conference on the biology and culture of shrimps and prawns, Mexico City, 1967 June 12-21. Rome: Food and Agriculture Organization of the United Nations. FAO Fish Rep. 57; 1969; 1015-1026.

DISCUSSION

Question: A question directed to Joan Browder: If you would, share some of your plans perhaps for continuing your research.

Answer: We were thinking that the study could have five data-gathering elements; one would be the monitoring of freshwater flow rates. Two would be measuring of vertical profiles of salinity, temperature, oxygen, and current direction and velocities. Three would be the measures of the detrital biomass and detritus decomposition rates. Four would be the mapping of the isohalines and the quantification of the area between isohalines periodically during the nursery season. This is where we would utilize the remote sensing techniques in combination with some field measurements. Five would be mapping and quantificaton of potentially productive habitat areas based on physical and biological features at different levels of high tide. This is measuring the stationary habitat features, the areal stationary habitat that we consider to be important to different estuarine organisms. And then the monitoring of fishery yield and effort would be number six. In addition, of course, we should not neglect to measure the input rates of the detritus, the nutrients, and sediments and toxic compounds because we need to keep tabs on these too. Now, some of the potential relationships that should be explored through both statistical analysis and computer modeling once we begin to gather this data are production area, which we have defined as the area of overlap of the favorable salinity band and the favorable stationary physical and biological habitat features. Look at that versus freshwater flow during the nursery season. Look at stratification versus freshwater flow, look at production areas versus stratification, look at fishery production versus production area, and look at fishery production versus the area of marsh. Look at detrital decomposition versus stratification or degree of stratification. And look at recruitment into the estuary versus the currents that occur during critical periods of post larval transport. And then look at fishery production versus water quality.

TEXAS SHRIMP FISHERIES AND FRESHWATER INFLOW

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ABSTRACT

The shrimp industry is a significant industry in Texas. The economic impact of shrimp to this State was approximately one-half billion dollars in 1979. The continued viability of this fishery is directly related to the well being of the critical marsh and estuarine habitats. Water managers must therefore consider this impact in all planning processes.

INTRODUCTION

The State of Texas has long held a reputation as a major producer of animal protein for the Nation. While in the public's mind this notoriety might be thought to result from only the production of beef, it should be noted that Texas is also a leader in the harvesting of seafood. According to statistics supplied by the National Marine Fisheries Service in their publication Fisheries of the United States 1979, Texas produced 84.9 million pounds of seafood in 1979 with a value of $160.2 million. Of this, approximately 42 million pounds were shrimp with a value of $152 million (Farley personal communication). This exvessel value represents an economic impact of approximately $500 million per year.

HISTORY OF THE SHRIMP FISHERY

The shrimp fishery originated in the bays and estuaries of the Gulf of Mexico. Fishery pioneers used large drag seines set close to shore and hauled by men or horses.

Using this method, shrimp fishing was worthwhile only when shrimp were abundant near shore. The otter trawl was introduced into the shrimp fishery between 1912 and 1917. Using this gear, the fishermen continued to shrimp entirely in bays and shallow water, however, the otter trawl did reduce the seasonality of the fishery. Eventually, the industry expanded and fishing grounds in the offshore region were discovered.

As the industry developed from its conception along the coastal shores to its current status as a multi-million dollar contributor to the economy, two distinctive forms emerged. These forms are known as the bay shrimp industry and the gulf shrimp industry. Each industry has its own character and personality. In addition, harvesting practices vary considerably in the two groups based on the importance of the particular shrimp species and the growth period within which harvesting takes place.

There are three species of shrimp which basically support the commercial shrimp fishery. These are Penaeus aztecus Ives, the brown shrimp, Penaeus setiferus Linnaeus, the white shrimp, and Penaeus duorarum Burkenroad, the pink shrimp in the Gulf of Mexico (Van Lopik et al. 1980). Adult brown shrimp and, in some cases, white shrimp are caught by the offshore operators while juvenile brown shrimp and white shrimp are caught by the inshore shrimpers.

The annual catches of these dominant species tend often to be highly variable, associated to a great degree with environmental conditions. The effects of the environmental factors on the brown, white and pink shrimp are most pronounced during their critical estuarine-growth phase (Van Lopik et al. 1980).

RELATIONSHIP OF THE SHRIMP INDUSTRY TO FRESHWATER INFLOWS

To understand the importance of freshwater inflows and the resulting marsh area vitality to the shrimp industry, it is necessary to review the life cycle of the commercial penaeid shrimp. Current thought is that these shrimp spawn offshore in the Gulf of Mexico. The eggs hatch into the first of three larval stages. For 15 to 20 days, the shrimp larvae drift helplessly with the prevailing currents, hopefully terminating their journey at the entrance to a bay system. The larval shrimp then molt into postlarvae and begin another migration to the upper bays and estuarine areas. With favorable conditions, the juvenile shrimp grow rapidly in these areas. As the shrimp near maturity they begin to migrate through the bays and reenter the Gulf. Here spawning takes place and the cycle is reinitiated.

According to Van Lopik et al. (1980), the weakest link in this cycle is the estuarine-growth phase. In this area, local fluctuations in temperature and salinity could potentially drastically effect both the availability of marsh suitable for growth and the actual growth rate of the shrimp. In addition, man-made alterations such as impoundments, bulkheading and alterations in freshwater discharges can accentuate the fluctuations causing considerably more detrimental impact.

Turner (1977) has observed that there is a direct relationship between actual marsh acreage and yield of shrimp. This work is in harmony with that of Barrett and Gillespie (1973) which shows that the annual brown shrimp production in Louisiana is correlated with the acreage of marsh having waters above 10 ppt salinity.

It appears from these findings that yields of the three major commercial species of shrimp in the Gulf of Mexico are dependent on maintenance of healthy estuarine marshes, mangrove areas and grassbeds in their natural state. Specifically, these areas provide postlarval, juvenile and subadult shrimp with food and protection from predators as well as assist in maintenance of the essential gradient between fresh and salt water (Van Lopik et al. 1980).

A key element to the vitality of a marsh or estuary is in its very definition which speaks to the need for fresh water (Chapman 1972). This mixing of river waters and seawater creates a nutrient sink of sulfates, carbonates, phosphorus and nitrogenous compounds (Copeland 1966). In addition, large amounts of detritus are washed into the estuary by the river flow. This detritus is a principal element in the food web of estuarine ecosystems (Copeland 1966).

There is some evidence that the various species of shrimp differ in their affinity to freshwater inflow as it is translated into salinity regimes. In fact, Gunter et al. (1964) have shown that salinity may be a limiting factor in the distribution and abundance of the commercially important penaeid species. In their studies, juvenile P. aztecus were most abundant in estuarine waters of 10 to 20 ppt salinity whereas P. setiferus were more abundant in waters below 10 ppt and P. duorarum tended to reach a larger abundance in waters greater than 18 ppt. These observed preferences are clearly depicted in species composition of the catch. Statistics tend to show the greatest concentration of brown shrimp to be off Texas where bay salinities are generally higher. In Louisiana white shrimp are dominant due in part to the relative freshness of the inside waters, while pink shrimp appear to be more abundant in the catch off southern Florida where salinities approach oceanic conditions (Gunter et al. 1964). Gunter and Hildebrand (1954) showed a correlation between the catch of white shrimp on the Texas coast and the average rainfall for the State. Their results show a significant correlation between the rainfall of the previous two years and the catch of white shrimp. Copeland (1966) also showed that an increase by similar fluctuations in shrimp catch, generally after a two year period.

Williamson (1977) stated that in San Antonio Bay, brown shrimp abundance in May through July was not affected by inflows in the May to June period or those from the previous September and October time frames. White shrimp on the other hand did vary positively in August with increases in the spring inflows. There also appeared to be some enhancement of white shrimp numbers by fall inflows of the previous year.

White and Perret (1973) showed that the timing of inflow is also important. In their evaluation of the effects of the Toledo Bend Project on Sabine Lake, they attributed the reduction in catch for the brown and white shrimp to operational procedures of the dam. Historically, heavy discharges occurred during spring and tapered off during the summer. The operating procedures of the dam changed this pattern by holding back the inflow surge until mid-May. This alteration has produced a near freshwater situation within Sabine Lake which has devastated the brown and white shrimp populations.

IMPLICATIONS TO PLANNING AND MANAGEMENT

There continue to be ever increasing demands for the available surface water. Frequently the need to allocate water to the estuary is overlooked. Fortunately, it appears that many water managers now see the need for considering freshwater and associated nutrient flows into the marsh areas to preserve the valuable fishery resources. Water certainly is a precious commodity which has long been taken for granted. Water uses must be more efficiently managed. No doubt there are methods of managing flows into estuaries to preserve or even enhance the fisheries.

As was mentioned above, brown and pink shrimp tend to prefer a higher salinity than do white shrimp. Because brown shrimp tend to dominate the Texas catches the water manager might justify increased allocation of surface water upstream in order to increase the salinity and thereby benefit the brown shrimp. The fallacy in this position is that such actions would be to the detriment of the white shrimp crop. Under the current situation, the population of brown shrimp and white shrimp tend to complement each other. Much as a farmer planting two crops, if one fails due to unfavorable environmental conditions the other may be successful enough to carry the farmer to the next season. The major crops in the the case of the Texas shrimp fishery are brown and white shrimp. Although brown shrimp are reported to spawn throughout the year, the high spawning periods are distinct from those of the pink or white shrimp. The staggered nature of peak spawning periods between the available species allows for the possibility of maintaining vitality within the resource. Uncontrollable environmental conditions may impact one crop but not the other.

Another consideration in maintaining both the brown and white shrimp populations is the socioeconomics of the industry. While it is true that brown shrimp represent the higher level of catch, the white shrimp populations continue to be harvested by the small near-shore operators especially during the fall open season in the bays where white shrimp are predominant in the harvest.

The more effective management of inflow to estuaries might be a solution to the ever increasing requirements placed on surface water. This effort however, must be based on sufficient information to maintain and enhance the important marine fisheries.

CONCLUSIONS

Sufficient information is available to show the importance of freshwater inflow to the vitality of the Texas shrimp industry. While ever-increasing requirements are being placed on the surface water resources, the need for balanced salinity regimes as well as sufficient nutrient and sediments to maintain a sound habitat should be paramount in the allocation process.

Water management agencies, fishery resource protection agencies and the fishing industry should maintain a close working relationship to insure vitality of the estuaries and the significant fisheries resource.

LITERATURE CITED

Barrett, B.B.; Gillespie, M.C. Primary factors which influence commercial shrimp production in coastal Louisiana. La. Dept. Wildlife and Fish. Tech. Bull. 9:28; 1973.

Chapman, C. R. The impact on estuaries and marshes of modifying tributary runoff. Chabreck, R.H., ed. Proceedings of the coastal marsh and estuary management symposium. 1972: 236p.

Copeland, B.J. Effects of decreased river flow on estuarine ecology. J. Water Poll. Contr. Fed. 1831-1839:1966.

Gunter, G.; Christmas, J.Y.; Killebrew, R. Some relations of salinity to population distributions of motile estuarine organisms with special reference to penaeid shrimp. Ecology 45(1): 181-185; 1964.

Gunter, G.; Hildebrand, H.H. The relation of total rainfall of the State and catch of the marine shrimp (Penaeus setiferus) in Texas waters. Bull. Mar. Sci. Gulf Caribb. 4:95; 1954.

Farley, O. Personal communication. National Marine Fisheries Service, Galveston, Texas. 1980.

Turner, R.E. Intertidal vegetation and commercial yields of penaeid shrimp. Trans. Am. Fish. Soc. 106:411-416; 1977.

White, C.J. Perret, W.S. Short term effects of the Toledo Bend Project on Sabine Lake, Louisiana. Proc. of the 27th Annu. Conf. S.E. Ass'n of Game and Fish Comm. 1973; 710.

Williamson, S.C. Penaeid shrimp abundance and riverine flow in San Antonio Bay, Texas. Proc. of the 31st Annu. Conf. Southeast Assoc. of Game Fish Comm. 1977; 522.

Van Lopik, J.R. et al., Fishery management plan for the Gulf of Mexico United States waters. Tampa, FL: Gulf of Mexico Fishery Management Council, 1980.

AN EVALUATION OF AQUATIC LIFE FOUND AT FOUR HYDRAULIC SCOUR SITES IN THE COLUMBIA RIVER ESTUARY SELECTED FOR POTENTIAL SEDIMENT DEPOSITION

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ABSTRACT

Substantial scouring of estuarine sediment occurs from flushing of a major river system with an annual spring freshet of 20,300 m^3/s. The effect is heightened by diurnal marine water intrusion combined with spring tides having ranges exceeding 3 m. Estuary depth is maintained by these forces at the end of jetties, promontories, and adjacent bridge openings. Hydraulic stress in these areas suggests biological instability, a low standing crop and occupancy by species tolerant of such physical conditions. Because inwater sediment disposal at sites with low biological activity is preferable to deposition at biologically rich and stable sites, scour sites were investigated for potential dredge deposition. Biological inventories of aquatic life were conducted in October, November 1978 and May 1979, at four diverse scour sites in the Columbia River estuary, river km 4 to river km 24. Investigative timing was related to the completion and initiation of normal maintenance dredging.

Benthic infauna, epifauna, and pelagic fish were studied as well as food utilization of dominant finfish. The 71 sampling efforts produced 42 species of finfish consisting of 31,870 individuals. Also captured in this sampling were 4 species of decapod crustaceans representing 4,957 epifauna. Numerically important benthic invertebrates included amphipods and copepods. Inventory studies indicated low suitability for sediment deposition due to biological richness at the Tongue Point and Interstate Bridge sites. Jetty A site was biologically poor, and has potential suitability as a deposition site. Tansy Point site may be suitable for depositon at predetermined times. Inventory evaluation studies should be tested under controlled deposition conditions preceding sustained usage.

INTRODUCTION

High volume flows characterize the Columbia River, the Nation's second greatest river and the largest flowing into the Pacific Ocean from the Western hemisphere. High flows are particularly noticeable from late May to early July as snow melt runoff from several mountain ranges averages 20,300 m^3/s. The effect is magnified by spring tides that exceed 3 m. Estuarine hydraulic forces combine to naturally deepen sites adjacent to jetties, peninsulas, or bridge openings. Dredging is never required at these sites since navigation channel depths may be exceeded by 3 m to 20 m.

There is an annual removal of 3,000,000 m^3 of sediments from the lower Columbia river estuary with most returned to the water. Estuarine sediment deposition can adversely impact many groups and species of aquatic life. Particle size change, smothering, and reintroduction of toxic substances are several factors which can alter a natural biological system. The National Marine Fisheries Service (NMFS) is vitally interested in minimizing adverse impacts to economically important fish as well as food organisms they utilize. The Corps of Engineers (COE) is charged with the responsibility of maintaining a 12-m deep, 180-m wide (40ft x 600ft) navigation channel for ocean shipping through the Columbia River estuary. The principal means of sediment removal to river km 32 is by hopper dredge which results in an inwater disposal. Sediment disposal of material dredged near the mouth is often placed in the ocean but several sites are utilized within the estuary. Concern over the continuing effect of dredge material on demersal finfish and shellfish by NMFS and COE suggested the agencies investigation of alternative sites.

In an earlier NMFS study, Durkin (1975) indicated relatively few finfish and shellfish off the Columbia River's North Jetty, whereas comparable sampling at nearby sites revealed greater numbers of fish. These results seemed to indicate the water turbulence off the North Jetty caused biological instability resulting in a low standing crop of demersal organisms. This concept, when applied to an estuarine situation, indicates use of similar habitats for sediment deposition rather than continued use of existing controversial inwater disposal sites.

A biological inventory of several hydraulically dynamic sites by NMFS was proposed to the Portland District COE in order to determine if estuarine hydraulic scour sites normally had low biological standing crop, were unstable, and supported species tolerant of stress. The concept was accepted by the COE, and inventory sampling was scheduled for the conclusion and beginning period of normal hopper dredging activity. It was emphasized by NMFS that should a site have apparent biological deficiencies more intensive sampling would precede and follow any deposition test by COE hopper dredges.

METHODS AND MATERIALS

Four sites were selected for inventory studies, each near the navigation channel and in the lower 18 miles of the estuary (Figure 1). Sites were named after nearby land promontories or structures. Thirty pelagic finfish surveys were made with a 200-m purse seine whereas forty demersal finfish surveys were made with an 8-m shrimp trawl. Each sample effort was five minutes in duration. Purse seine and trawl sets

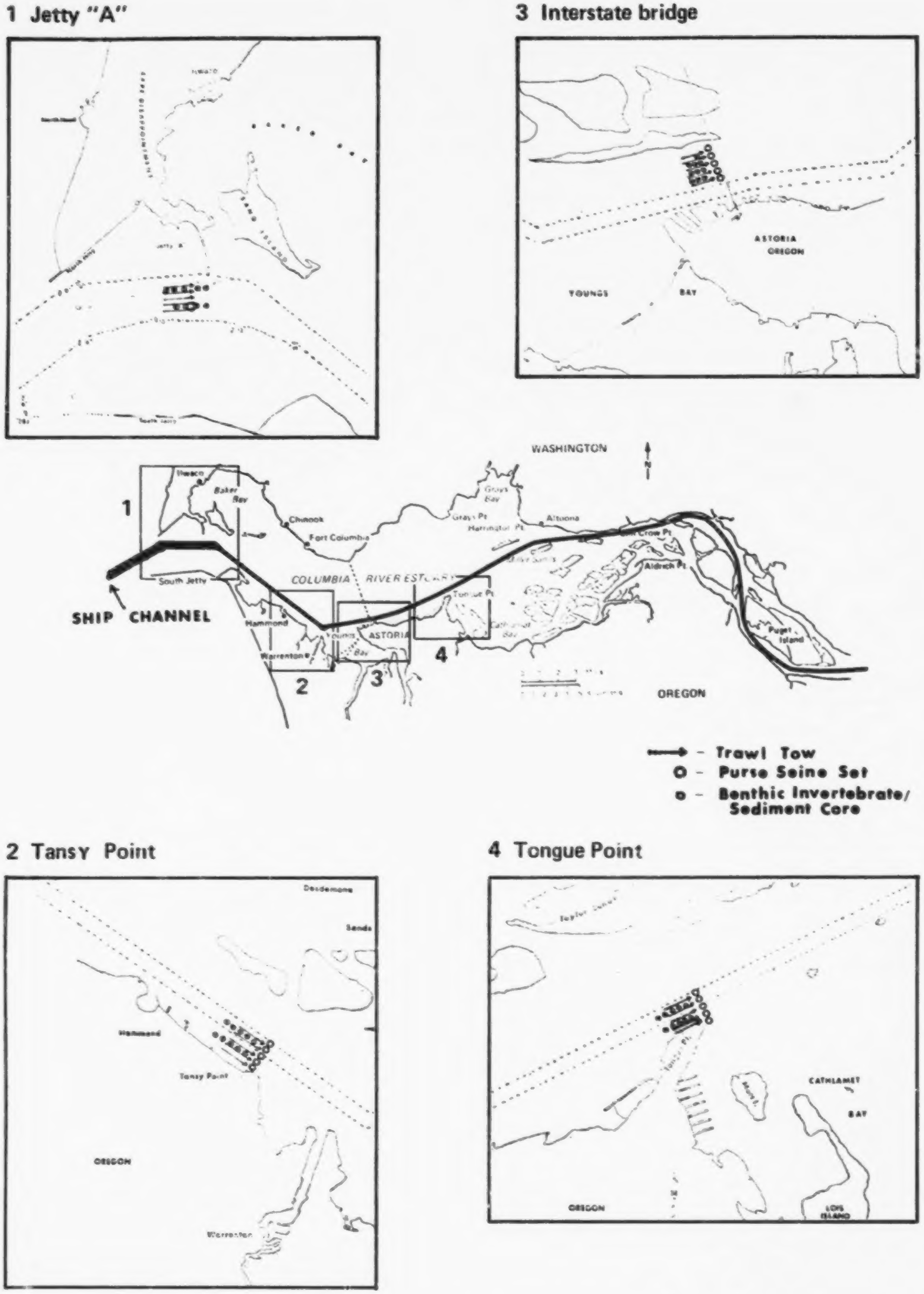
1 Jetty "A"
3 Interstate bridge
ASTORIA OREGON
YOUNGS
BAY
WASHINGTON
N
1
Ilwaco
Baker Bay
Chinook
Fort Columbia
Grays Bay
Grays Pt
Harrington Pt
Altoona
Crow Pt
Aldrich Pt
South Jetty
COLUMBIA RIVER ESTUARY
SHIP CHANNEL
Hammond
Warrenton
Youngs Bay
ASTORIA
Tongue Pt
Cathlamet Bay
Puget Island
2
3
4
OREGON
- Trawl Tow
O - Purse Seine Set
o - Benthic Invertebrate/ Sediment Core
2 Tansy Point
Desdemona
Sands
Hammond
Tansy Point
OREGON
Warrenton
4 Tongue Point
CATHLAMET
BAY
OREGON

Figure 1.--The Columbia River estuary with the sampling effort shown for the four hydraulic scour sites.

were made in an upstream or easterly direction but trawling was undertaken specifically during flood tide conditions. During the two survey periods, October/November 1978 and May 1979, there were five trawl sets and five purse seine hauls made at each site. An exception occurred at Jetty A where hazardous wave action and tidal currents prevented the purse seine effort.

Finfish were identified to species, anesthetized, examined, measured in millimeters and weighed in grams either aboard the vessel or at the Hammond laboratory. In each sample up to 50 randomly selected individuals of each species were selected for length/weight frequency measurement and up to ten were sacrificed for stomach content determination. Decapod crustaceans such as crab and shrimp were weighed and measured.

Specimens retained for food-utilization studies were injected with Formalin (Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.) into the stomach immediately after capture. The stomach was later removed between the esophagus and pyloric sphincter, contents placed in 70 percent alcohol and examined with a 10-power microscope. Food items were identified to the lowest possible taxon, air dried, and weighed to the nearest 0.0001 gm.

Benthic infauna, captured with a 0.05-m^2 Ponar sampler, were washed free of sediments, retained on a 0.595-mm sieve, and fixed in a 10 percent Formalin-rose bengal stain solution. A series of 10 samples taken at each of four sites during both survey periods resulted in 80 samples. All invertebrates were identified, sorted into groups, counted and weighed. Similar groups were air dried for 10 minutes, weighed to the nearest 0.0001 gm and preserved in an alcohol-glycerin solution.

Sediment samples were gathered during each benthic invertebrate survey. Ten substrate samples were collected at each site during each survey, for a total of 80 samples. Temperatures and salinities were taken on the bottom and surface at each site and survey with a Beckman RS5-3 salinometer. Sediment samples were refrigerated and transferred to a private analytical laboratory for determination of particle texture components and total volatile solids. Particle-size categories followed the Wentworth scale described by Twenhofel and Tyler (1941) and were listed in percentage weight of the total sample.

RESULTS

FINFISH AND DECAPOD CRUSTACEAN EVALUATION

The various species of fish and decapod shellfish captured during trawl and purse seine sampling are presented in Table 1. The list includes 47 species with 37 appearing in trawl catches and 22 in purse seine catches. The fall 1978 trawling survey averaged 56.3 finfish and 78.5 shellfish per minute of sampling effort whereas the May 1979 survey yielded considerably less with an average 7.5 finfish and 84.7 shellfish for

TABLE 1.--Finfish and decapod shellfish captured with purse seine and trawl nets during sampling at four hydraulic scour sites in the Columbia River estuary Oct./Nov. 1978-May 1979

		Number 1978		Number 1979		
COMMON FISH	SCIENTIFIC NAME	Trawl	Purse Seine	Trawl	Purse Seine	Total
Pacific lamprey	Entosphenus tridentatus	-	-	4	4	8
Spiny dogfish	Squalus acanthias	2	-	-	-	2
White sturgeon	Acipenser transmontanus	1	-	1	-	2
American shad	Alosa sapidissima	-	571	-	156	727
Pacific herring	Clupea harengus pallasi	2	17343	-	228	17573
Northern anchovy	Engraulis mordax	127	2183	29	16	2355
Chum salmon	Oncorhynchus keta	-	-	-	9	9
Coho salmon	Oncorhynchus kisutch	-	3	1	1473	1477
Sockeye salmon	Oncorhynchus nerka	-	-	-	9	9
Chinook salmon "0"	Oncorhynchus tshawytscha	-	95	-	1151	1246
Chinook salmon "I"	Oncorhynchus tshawytscha	-	6	-	450	456
Cutthroat trout	Salmo clarki	-	-	-	13	13
Rainbow (steelhead) trout	Salmo gairdneri	-	-	-	173	173
Whitebait smelt	Allosmerus elongatus	1	-	5	-	6
Surf smelt	Hypomesus pretiosus	-	190	-	898	1088
Longfin smelt	Spfrinchus thaleichthys	3719	4	2	314	4039
Eulachon	Thaleichthys pacificus	-	1	-	3	4
Peamouth	Mylocheilus caurinus	-	-	-	32	32
Largescale sucker	Catostomus macrocheilus	-	-	5	2	7
Pacific tomcod	Microgadus proximus	497	-	275	2	774
Walleye pollock	Theragra chalcogramma	-	-	5	-	5
Threespine stickleback	Gasterosteus aculeatus	-	39	-	27	66
Bay pipefish	Syngnathus griseolineatus	1	-	-	-	1
Redtail surfperch	Amphistichus rhodoterus	5	-	-	-	5
Shiner perch	Cymatogaster aggregata	553	65	5	11	634
Spotfin surfperch	Hyperprosopon anale	4	-	-	-	4
Snake prickleback	Lumpenus sagitta	18	-	63	-	81
Saddleback gunnel	Pholis ornata	31	-	1	-	32
Pacific sand lance	Ammodytes hexapterus	-	-	1	-	1
Vermillion rockfish	Sebastes miniatus	-	-	1	-	1
Padded sculpin	Artedius fenestralis	-	-	1	-	1
Prickly sculpin	Cottus asper	29	-	26	-	55
Buffalo sculpin	Enophrys bison	1	-	-	-	1
Pacific staghorn sculpin	Leptocottus armatus	315	1	166	1	483
Warty poacher	Occella verrucosa	1	-	3	-	4
Pricklebreast poacher	Stellerina xyosterna	5	-	25	-	30
Showy snailfish	Liparis pulchellus	-	-	21	-	21
Pacific sanddab	Citharichthys sordidus	1	-	-	-	1
Speckled sanddab	Citharichthys stigmaeus	1	-	4	-	5
Butter sole	Isopsetta isolepis	6	-	1	-	7
English sole	Parophrys vetulus	20	-	20	-	40
Starry flounder	Platichthys stellatus	255	6	81	13	355
Sand sole	Psettichthys melanostictus	33	-	4	-	37
	Sub Total	5628	20507	750	4985	31870

COMMON DECAPOD CRUSTACEANS	SCIENTIFIC NAME	Trawl	Purse Seine	Trawl	Purse Seine	Total
Sand shrimp	Crangon franciscorum	1881	0	2218	19	4118
Sand shrimp	Crangon stylirostris	169	0	289	-	458
Sand shrimp	Crangon nigromaculata	7	0	-	-	7
Dungeness crab	Cancer magister	161	0	213	-	374
	Sub Total	2218	0	2720	19	4957
	TOTAL	7846	20507	3470	5004	36827

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each minute of effort. The purse seine effort in 1978 produced 274.8 finfish per minute of effort due to a large catch of Pacific herring at Tongue Point while the May 1979 survey averaged 66.4 finfish per minute. Catch results indicated both substantial numbers of finfish and species diversity at sample sites. Economically important species were common and included coho salmon, Oncorhynchus kisutch; chinook salmon, O. tshawytscha; starry flounder, Platichthys stellatus; American shad, Alosa sapidissima; and Pacific herring, Clupea harengus pallasi.

A summary of species and numbers captured at each site is shown in Table 2. Grouped weights are included to provide further assessment of catch results. Purse seine catches at the Tongue point site had substantially more pelagic fish than other areas in October and May. Trawl catches revealed the Interstate Bridge site had the highest number of demersal finfish, but many were also found at Tongue Point. The Dungeness crab, Cancer magister, was abundant at Tansy Point. Overall, the catch results indicated Tongue Point had a high biological value in terms of fish and crustaceans.

Several important finfish species captured in this study were examined to determine if their sizes and food utilization were comparable between the sample sites. The five species, chinook salmon, Pacific herring, American shad, Pacific tomcod, Microgadus proximus, and Pacific staghorn sculpin, Leptocottus armatus, represent 66.7 percent of all finfish captured. Shad and herring represent pelagic species while chinook salmon occur in both pelagic and intertidal habitats, whereas tomcod and staghorn sculpin are demersal fish.

Pacific herring populations consisted of at least two age groups in the October 1978 survey, with larger fish in the marine habitat and smaller fish at the freshwater site (Figure 2). The modified Index of Relative Importance (IRI), described by Pinkas (1971), indicated herring were actively feeding on calanoid copepods, but only at Tongue Point. In the May 1979 survey, a single herring age group predominated at Tansy Point and the Interstate Bridge. Zooplankton was the principal diet though a substantial proportion of fish examined had not eaten.

American shad were also represented by two distinct age groups but they were present during both surveys (Figure 3). It was evident the age groups had increased in length several centimeters between October and May. The IRI indicated the importance of unidentified plant material consumed at the upper three sites during the fall survey. At Tongue Point where most shad were found, however, calanoid copepods were also an important food item. In May 1979, shad consumed the benthic amphipod Corophium salmonis and calanoid copepods at Tongue Point and Tansy Point. Copepods were the important identifiable food item at the Interstate Bridge where most shad were captured.

Chinook salmon length frequency and IRI categories are shown in Figure 4. Only subyearling fall chinook were encountered in the 1978 survey with most taken at Tongue Point. Identifiable food items at that site were primarily insects. The May 1979 chinook catch consisted of subyearling fall chinook, yearling spring chinook and a few residuals. Diet of all the

Table 2. --A summary of finfish and shellfish taken at four sampling sites in the Columbia River estuary during an evaluation study of hydraulic scour sites

	Jetty A	Tansy Point	Interstate Bridge	Tongue Point	TOTAL
October					
TRAWL CATCH					
Finfish species	18	9	12	10	24
Decapod species	4	2	2	1	4
Finfish numbers	186	244	3610	1588	5628
Decapod numbers	228	321	148	1521	2218
Finfish weight gm	11681	4770	71388	27560	115399
Decapod weight gm	3882	16748	12140	1350	34120
May					
TRAWL CATCH					
Finfish species	13	15	4	6	25
Decapod species	3	2	2	0	3
Finfish numbers	84	458	174	34	750
Decapod numbers	460	2239	21	0	2720
Finfish weight gm	1710	27313	9163	5442	43628
Decapod weight gm	4960	51372	68	0	56400
October					
PURSE SEINE					
Finfish species	--	9	8	10	13
Decapod species	--	0	0	0	0
Finfish numbers	--	2378	71	18058	20507
Decapod numbers	--	0	0	0	0
Finfish weight gm	--	58576	2946	187630	249152
Decapod weight gm	--	0	0	0	0
May					
PURSE SEINE					
Finfish species	--	16	17	13	21
Decapod species	--	1	1	0	1
Finfish numbers	--	1652	1162	2172	4986
Decapod numbers	--	2	17	0	19
Finfish weight gm	--	22285	45057	48010	115352
Decapod weight gm	--	5	59	0	64

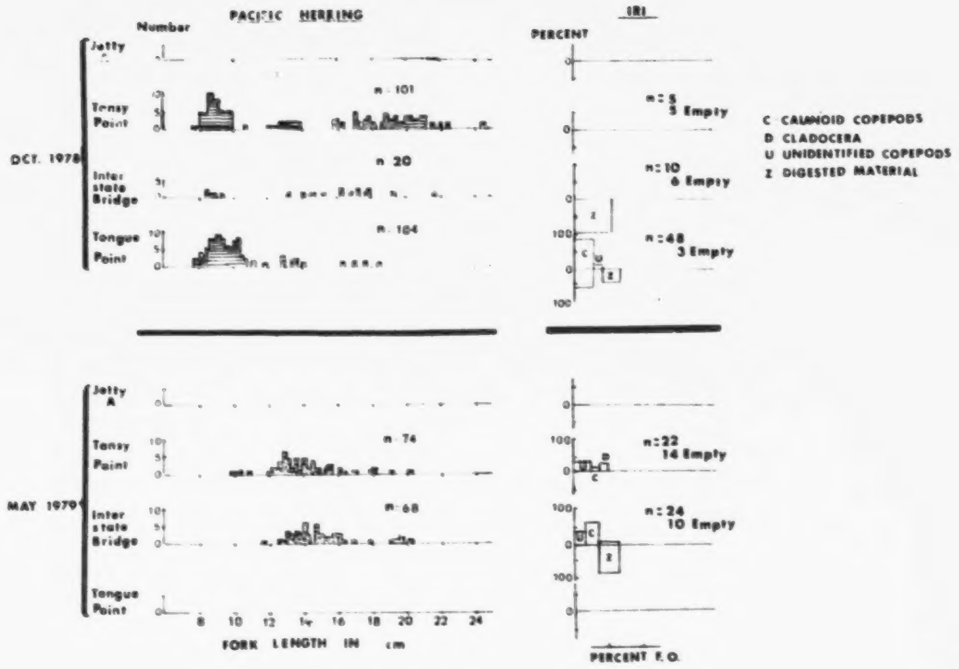
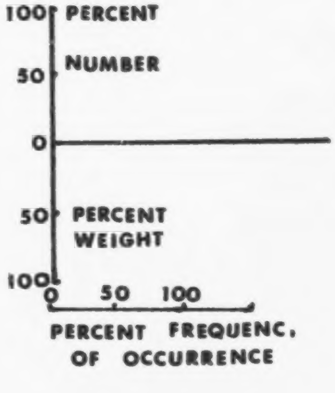


Figure 2. Length frequency and food habits of Pacific herring captured at four estuarine hydraulic scour sites during two surveys. The IRI diagram for this and the following four figures shows numerical percent of food organisms above the horizontal line, the percent weight below the horizontal line, and width of the box represents the percent frequency of occurrence of the item in stomachs (see enlarged diagram below).

Index of Relative Importance (IRI) numerical value determination (N + W)F = IRI.


100
PERCENT
50
NUMBER
0
50
PERCENT
WEIGHT
100
0
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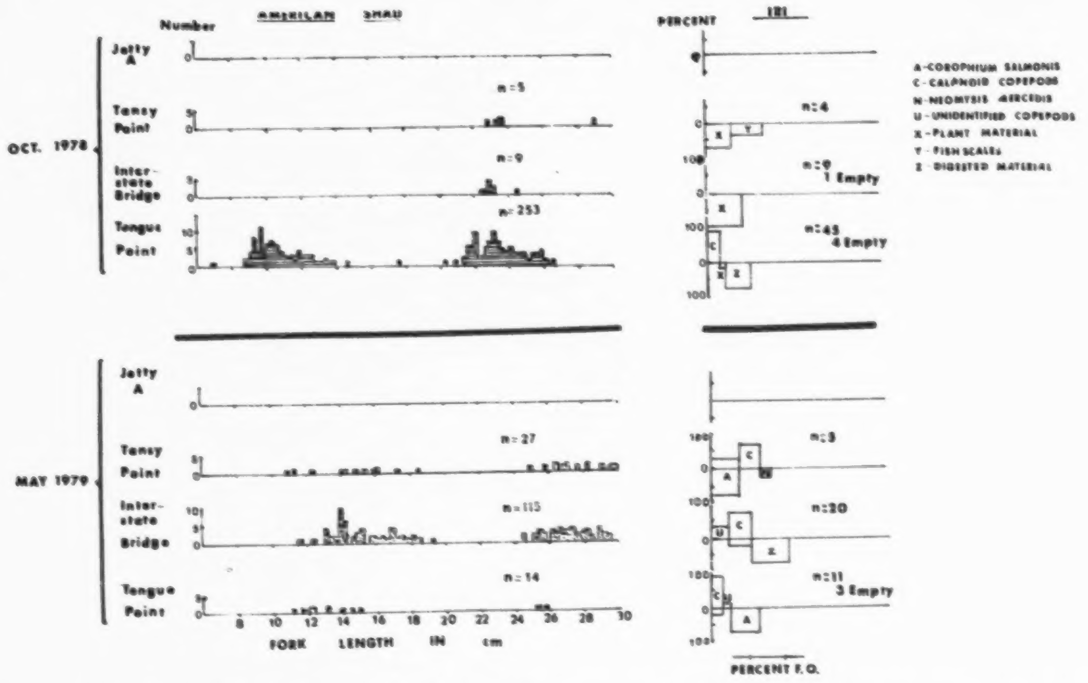

Figure 3. Lengths and food use of American shad captured during two surveys at four Columbia River estuarine sites.

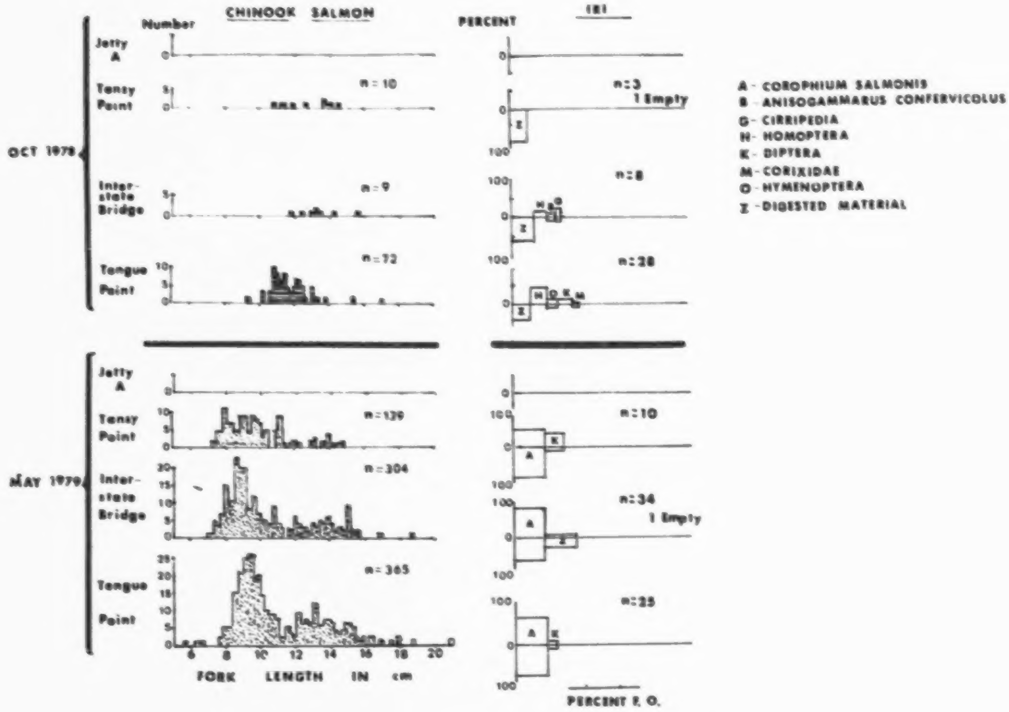

Figure 4. Lengths and food use of chinook salmon.

young salmon was consistently the benthic amphipod, C. salmonis, at the three sites. Diptera was the other identifiable food item.

Pacific tomcod length frequency and IRI categories are shown in Figure 5. Most of the 1978 fish fall into two age groups though a smaller size group appears at Jetty A and a few larger fish at the Interstate Bridge. Prey items varied considerably between the four sites. The IRI indicated anchovy, amphipods, mysids, and crangon shrimp were all extensively utilized. The 1979 survey indicated tomcod were present at the two marine stations, but only one age group was represented. Benthic amphipods and mysids were numerically important food items, whereas digested fish and crangon shrimp accounted for most of the weight.

The demersal Pacific staghorn sculpin size group and food utilization is shown in Figure 6. Intergradation of sculpin length obscured any size grouping during both surveys though the larger sculpin were found off Tongue Point in October and at Tansy Point in May. Epibenthic fauna diversity typified the diet of sculpin caught in October. Benthic amphipods, C. salmonis and Anisogammarus confervicolus, and fish were the essential diet items of sculpin in May.

Dietary organisms for the fish varied dramatically during the October survey depending upon species and where they were caught. The May survey results indicated a smaller selection of food items and substantial use of both calanoid copepods and benthic amphipods. The incidence of empty stomachs was somewhat less in the fish captured at upstream sites indicating higher availability of prey organisms in that area.

Particle size ranged from medium gravel (8mm) down to clay (0.00 to 2mm). The proportional average value of ten samples for each site was determined and plotted by size category (Figure 7). The unbroken lines indicate results from the fall 1978 survey, while the dotted lines represent results from May 1979. Several characteristics were noted. (1) Medium grain sand (0.25-0.5mm) was the major size category of sediments at all sites. (2) The high proportion of medium grain sand was unchanged at all sites between the two surveys. (3) Slightly higher proportions of both larger and finer sediments were found at sites above Jetty A. (4) The scour sites are essentially homogeneous substrate habitats with little evidence of sediment accumulation or seasonal change.

Total volatile solids (TVS) were analyzed in each sediment core with the range and average for each site and survey shown in Figure 7. The sediment was essentially clean sand with average levels of two percent or less, though two samples exceeded the EPA six percent level.

Averages of two water quality parameters (salinity and temperature) gathered with sediment and benthic infauna samples also appear in Figure 7. The values are represented from readings taken at the surface (S) or bottom (B). The salinity levels ranged from marine to fresh from Jetty A to Tongue Point, and from bottom to surface. Salinities change dramatically with season and

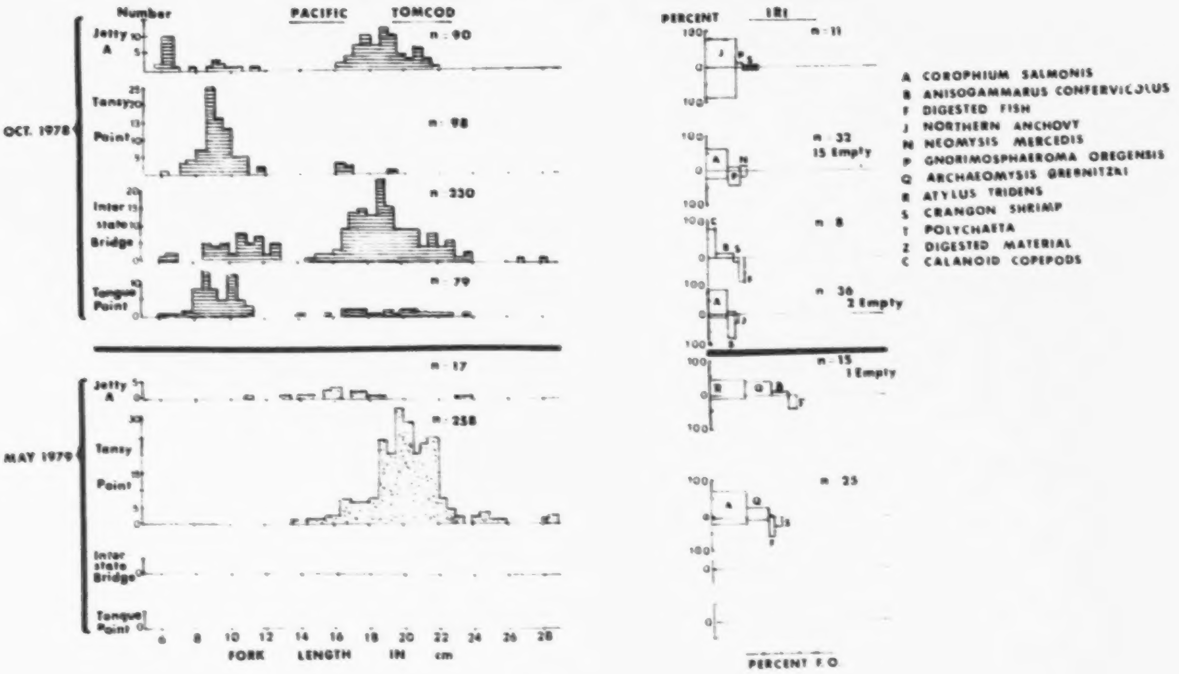

Figure 5. Length and food use of Pacific tomcod captured during two surveys at four Columbia River estuarine sites.

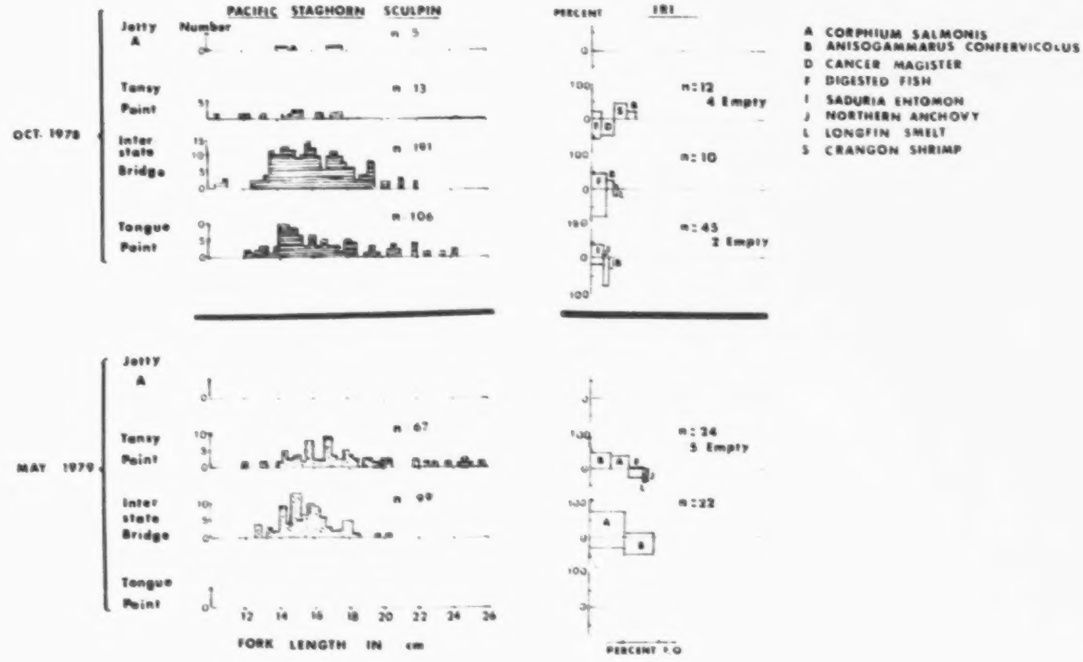

Figure 6. Length and food use of Pacific staghorn sculpin.

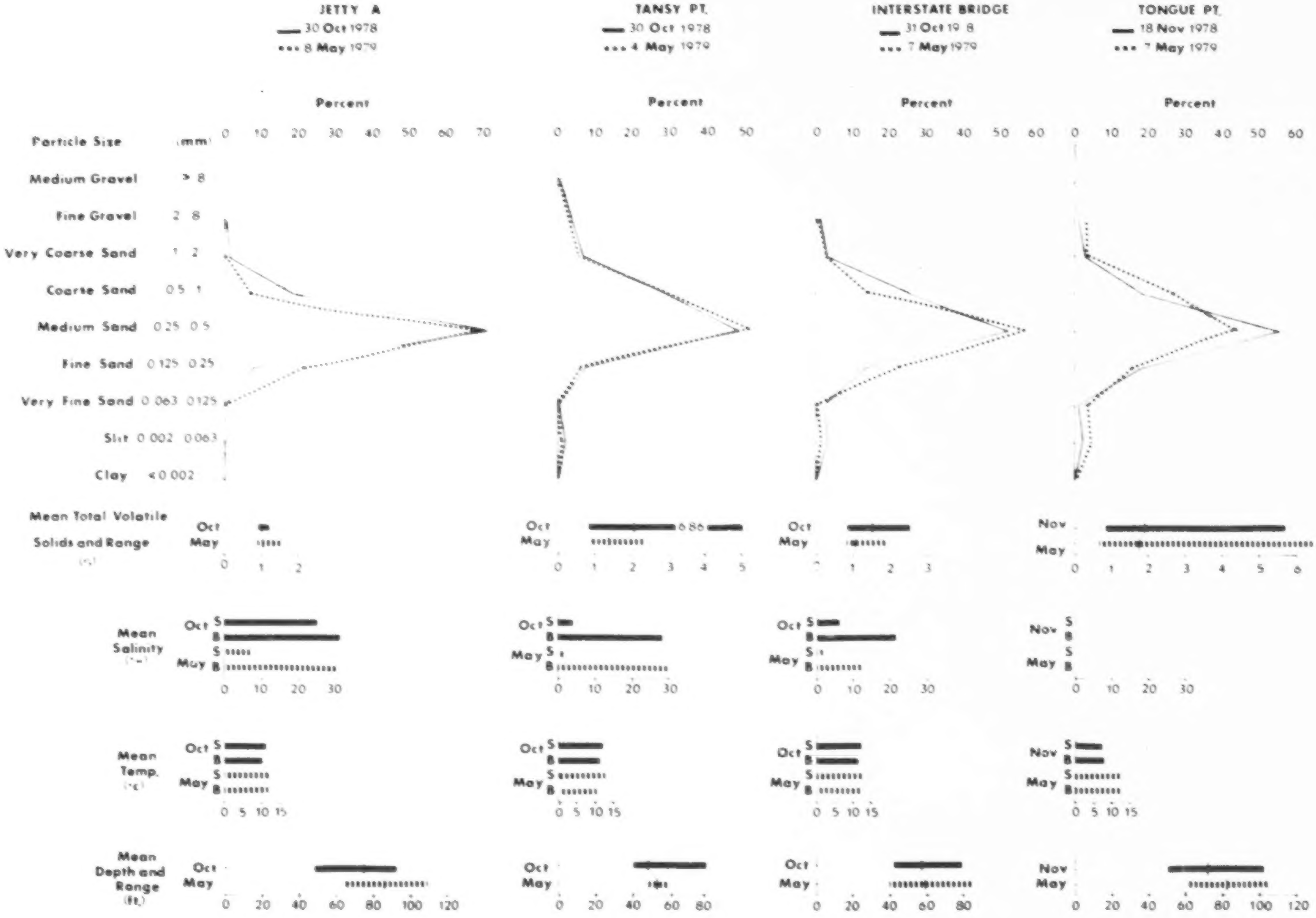

Figure 7. Physical conditions during benthic surveys at four scour sites in the Columbia River estuary.

water volume, however, in this study they were generally comparable at the time of the October and May surveys. Water temperatures were similar from surface to bottom through both surveys. Depths at sample sites were greater during the May survey and may reflect fresher runoff conditions.

BENTHIC INVERTEBRATES

Taxonomic groups and species captured in the 80 October and May samples are listed in Table 3. Included are the sites and surveys where they occurred. There were 43 groups or species listed with the highest diversity found at Tansy Point and the Interstate Bridge. Some epibenthic invertebrates species were captured with the infauna grab-sampler and others with the trawl. Epifauna include the bivalues Corbicula manilensis and Mytilus edulis, several species of mysids, crangon shrimp, Dungeness crab, copepods, cladocerans and Trichoptera.

Comparative abundance of benthic invertebrates is shown for the four sites and two survey periods in Table 4. The density of infauna organisms was low at all sites in October although copepod epifauna at the Interstate Bridge provided an appearance of numerical importance. The May survey results revealed greater infauna densities at all four sites. Increases occurred in nearly all groups, but particularly the Amphipoda, Nematoda, and Copepoda. The densities of organisms per m^2 were greater than previously reported in estuarine sampling studies at or near the navigation channel by Sanborn (1973, 1975), Higley and Holton (1975, 1978) and Durkin and Emmett (1980). However, scour area invertebrate densities were considerably lower than those found in nearby estuarine embayments by these same investigators.

CONCLUSIONS

Hydraulic forces which maintain water depths at the four study sites apparently result in a uniform substrate which accumulates little sedimentary material. Benthic infauna densities increased substantially between surveys though there was no obvious change in sediment particle size. Some of the sites appear to have substantial numbers of pelagic schooling fish, demersal fish and shellfish. Fish examined for food utilization consumed other fish, zooplankton, insects, a variety of epifauna, and benthic amphipods. The amphipod most frequently consumed, C. salmonis, is an infauna tube-dwelling species that apparently migrates into the water column because it was consumed by both pelagic and demersal fish.

On the basis of the inventory, the Jetty A site would be suggested as a test disposal site particularly in October and November, whereas Tongue Point would be excluded from further consideration. The Interstate Bridge site, though not as valuable as Tongue Point, should also be excluded from a test disposal effort. Tansy Point may have potential as a test disposal site though further evaluation is needed, particularly during the active dredging season. A test disposal program should provide for an evaluation of fisheries and infauna by preliminary and post disposal sampling. The

TABLE 3.--Benthic invertebrate and epifauna collected October-November 1978, and May 1979 at four scour sites in the Columbia River estuary.

	Jetty A	Tansy Point	Interstate Bridge	Tongue Point
Phylum Ctenophora	1,[a] 2[b]			
Phylum Platyhelminthes				
Class Turbellaria		2	1, 2	1, 2
Phylum Nemertea	1, 2	1, 2	1, 2	1, 2
Phylum Acanthocephala				2
Phylum Nematoda	1, 2	1, 2	1, 2	1, 2
Phylum Annelida				
Class Polychaeta				
Family Nephtyidae				
Nephtys californiensis	1, 2			
Family Nereidae				
Neanthes limnicola		2		1
Family Orbiniidae				
Haploscoloplos spp.		1, 2	2	
Family Phyllococidae				
Eteone dilatea		2		
Family Spionidae				
Polydora spp.		1		
Spio filicornis	2	1		
Family Capitellidae				
Capitella capitata			1	
Class Oligochaeta	2	1	1, 2	
Phylum Mollusca				
Class Gastropoda	2			1
Class Bivalvia				
Family Corbiculidae				
Corbicula manilensis		1	2	1, 2
Family Tellinidae				
Macoma balthica		1, 2	1, 2	
Family Mytilidae				
Mytilus edulis	1, 2	2		
Phylum Arthropoda				
Subphylum Mandibulata				
Class Crustacea				
Subclass Branchiopoda				
Order Cladocera	1	2	2	1, 2
Subclass Copepoda	1, 2	1, 2	1, 2	1, 2
Subclass Cirripedia				
Family Balanidae				
Balanus crenatus	2			

[a] Collected in October-November 1978

[b] Collected in May 1979

Table 3.--(Cont.)

	Jetty A	Tansy Point	Interstate Bridge	Tongue Point
Subclass Malacostraca				
Superorder Peracarida				
Order Mysidacea				
Family Mysidae				
Archaeomysis grebnitzkii	1, 2	1, 2	1, 2	
Neomysis mercedis	1	2	1, 2	1, 2
Acanthomysis macropsis	Trawl[c]			
Neomysis kadiakensis	Trawl			
Order Cumacea				
Family Diasiylidae				
Diastylopsis dawsoni	1, 2			
Family Leuconidae				
Hemileucon comes		2	2	
Order Isopoda				
Suborder Flabellifera				
Family Sphaeromatidae				
Gnorimosphaeroma oregonensis	1	1		
Suborder Valifera				
Family Idoteidae				
Mesidotea (=*Saduria*) *entomon*	2		2	1, 2
Idotea fewkesi			Trawl	Trawl
Order Amphipoda				
Suborder Gammaridea				
Family Corophiidae				
Corophium salmonis		1, 2	2	1, 2
Corophium spinicorne		1	2	
Family Gammaridae				
Anisogammarus confervicolus	1	1, 2	1, 2	1, 2
Family Haustoriidae				
Eohaustorius estuarius		2	1, 2	1, 2
Family Oedicerotidae				
Monoculodes spinipes	1, 2			
Family Phoxocephalidae				
Paraphoxus milleri		1, 2	1	
Superorder Eucarida				
Order Decapoda				
Suborder Natantia				
Family Crangonidae				
Crangon franciscorum	Trawl	Trawl	Trawl	
Crangon stylirostris	Trawl			
Suborder Reptantia				
Cancer magister	Trawl	Trawl	Trawl	
Class Insecta				
Order Diptera				
Family Chironomidae			2	2
Family Heleidae			2	2
Order Trichoptera		1		
Order Hymenoptera	1			
Phylum Chaetognatha	1, 2	2	2	

[c] *Species captured with 8 m shrimp trawl*

TABLE 4.--Abundance of various groups of benthic invertebrates in numbers per meter square as indicated by 10 ponar 0.05 m^2 grab samples at each of four sites during two survey periods.

	October 1978				May 1978			
GROUPS	Jetty A	Tansy Point	Interstate Bridge	Tongue Point	Jetty A	Tansy Point	Interstate Bridge	Tongue Point
Turbellaria			168	12		202	446	200
Nemertea	2	34	14	8	4	156	58	8
Nematoda	38	216	100	32	4486	704	756	1138
Acanthocephala								1
Polychaeta	6	40	14	6	56	60	8	
Oligochaeta			10		10		34	
Mollusca								
Gastropoda				2	4			
Bivalvia	2	10	8	76	2	34	12	18
Arthropoda								
Cirripedia					4			
Mysidacea	10	24	4		492	36	6	4
Cumacea	2				4	4	18	
Amphipoda	10	156	62	148	28	816	784	1830
Decapoda					10	36	22	24
Isopoda	2	6		2	2		6	2
Cladocera	4			20		2	76	40
Copepoda	36	36	2080	2	62	106	2810	3414
Insecta								
Diptera	2	4					8	28
Hymenoptera	4							
Trichoptera		2						
Other								
Ctenophora	4				30			
Chaetognatha	14				6	2	2	
Fish larvae	2					20	122	8
TOTAL	138	528	2460	308	5200	2178	5168	6716

Corps of Engineers should also monitor sediment particle movement from the test site to determine its fate. It is recommended that riverine and oceanic sites with hydraulic scouring be evaluated biologically to determine why some areas are rich in species and others are not.

ACKNOWLEDGEMENTS

This study was conducted with contractual assistance from the Portland District, U.S. Army Corps of Engineers, DACW 57-79-F-9145. We appreciate the cooperation and assistance of Jack Bechley, Navigation Division. Roy Pettit, Nick Zorich, and David Miller contributed essential effort in the studies data gathering phase while Sandy J. Lippovsky assisted with laboratory analysis of stomach contents. Imogene Abrahamson typed the manuscript and Jim Peacock prepared plates for the figures. We are indebted to these and other staff personnel in Hammond, and Prescott, Oregon and Seattle, Washington who supported this effort.

REFERENCES

Durkin, J.T. An investigation of fish and decapod shellfish found at four dredge disposal sites adjacent to the mouth of the Columbia River. Report to Portland District Corps of Engineers and NMFS Columbia River Program Office; 1975; 29p.

Durkin, J.T.; Emmett, R.L. Benthic invertebrates, water quality and substrate texture in Baker Bay, Youngs Bay and adjacent areas of the Columbia River estuary. NMFS. Coastal Zone and Estuarine Studies. 1980; 44p.

Higley, D.L.; Holton, R.L. Biological baseline data Youngs Bay, Oregon. Final Report 1 November 1973 through 30 April 1975. Corvallis, Oregon: School of Oceanography, Oregon State University, 1975; 75-6p.

Higley, D.L.; Holton, R.L. A grab-sample study of the benthic invertebrates of the Columbia River estuary. Supplemental data Rep. 1 November 1975 through 29 February 1976. Port of Astoria. 1978; 76-3p.

Pinkas, L.; Oliphant, M.S.; Iverson, I.L. Food habits of albacore, bluefin tuna, and bonito in California waters. California waters. Calif. Dept. Fish and Game; Fish Bull. 1971; 105p.

Sanborn, H.R. Benthic infauna observed at five sites in the Columbia River from August 19 73 to July 1974, Nat. Mar. Fish. Ser. Final Rep. to U.S. Army Corps of Engineers and Col. Riv. Prog. Off.; 1973; 19p.

Sanborn, H.R. An investigation of the benthic infauna at two dredge and four dredge disposal sites adjacent to the mouth of the Columbia River. Nat. Mar. Fish. Ser. Final Rep. U.S. Army Corps of Eng. and Col. Riv. Prog. Off; 1975; 15p.

Twenhofel, W.M.; Tyler, S.A. Methods of study of sediments. New York: McGraw-Hill Book Co.; 1941.

CHAPTER 7

FRESHWATER INFLOW STUDIES IN SOUTHERN TEXAS ESTUARIES

THE EFFECTS OF FRESHWATER INFLOW ON SALINITY AND ZOOPLANKTON POPULATIONS AT FOUR STATIONS IN THE NUECES-CORPUS CHRISTI AND COPANO-ARANSAS BAY SYSTEMS, TEXAS FROM OCTOBER 1972 - MAY 1975

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ABSTRACT

Between October 1972 and May 1975, two periods of major freshwater inflow (June-November 1973 and August and September 1974) affected zooplankton populations in the Nueces-Corpus Christi and Copano-Aransas Bay Systems. Inflows resulted in replacement of estuarine species with freshwater species and the lowering of salinities to near 0 parts per thousand (ppt). Populations of the calanoid copepod, *Acartia tonsa*, were lowest during maximum inflow but sharply increased following salinity increases as small as 1 to 3 ppt.

INTRODUCTION

During the period October 1972 through May 1975 the Texas Water Development Board and the City of Corpus Christi funded a project to monitor the effect of freshwater inflow on the phytoplankton, zooplankton, and benthic communities in the Nueces-Corpus Christi and Copano-Aransas Bay Systems. Increased municipal, agricultural, and industrial usage of fresh water prompted the need for research in determining requirements of freshwater inflow into Texas estuaries.

The study area was located within the south central climatological division (Texas Water Development Board 1968) between 27°40' and 28°10' north latitudes and 96°50' and 97°30' west longitudes. The average annual precipitation in this climatological division was 84.4 cm.

Aransas Bay, composed of Copano, Aransas, Redfish, St. Charles and Carlos bays, has about 5.7×10^4 ha and has an average of 81.3 cm annual rainfall (Texas Water Development Board 1968). Aransas Bay, historically, has received about $7.3 \times 10^8 m^3$ of fresh water annually. Physical characteristics of the Aransas Bay system, i.e. water circulation, drainage, and oyster reef distribution, are given by Parker (1959) and Gunter (1945). According to Gunter minimal amounts of water, if any, from the Nueces-Corpus Christi Bay intrude into the Aransas Bay system. Collier and Hedgpeth (1950) give a detailed analysis of the hydrography of the study area.

The Corpus Christi Bay system is composed of Nueces, Oso, and Corpus

Christi bays which total about 5.4×10^4 ha (Texas Water Development Board 1968). The average rainfall for this area is 76.2 cm annually. This bay, historically receives approximately 1.23×10^9 m^3 of fresh water annually. Descriptive studies of the Corpus Christi Bay system include Hood (1952) and Anderson (1980).

Thirty sample sites were established in such a pattern as to give the broadest possible coverage of the different areas and physical parameters (Figure 1). Although 30 stations were established only four were located in close proximity to major sources of freshwater inflow and these sites were selected to monitor freshwater inflow effects on zooplankton communities. Station 38-2 was located at the mouth of the Nueces River. Station 200-2 was at the entrance of Oso Bay. In Copano Bay, Station 44-2 was near the mouth of the Aransas River and Chiltipin Creek. Station 54-3 was at the entrance of Mission Bay.

MATERIALS AND METHODS

Zooplankton samples were collected with a 0.5-m #10 mesh (153 µ) nylon net. One-minute surface tows were made in a counterclockwise direction from the port side of the boat so that the net was towed clear of the boat's wake and wheelwash. The amount of water filtered was measured with a General Oceanic Model 2030 digital flowmeter attached in the center of the mouth of the net. Samples were preserved with 5 percent buffered Formalin.

In the laboratory, plankton samples were subsampled using a Hensen-Stemple pipette. Counts were made using a Wild M-5 dissecting microscope. Standing crops were expressed as total numbers of individuals per cubic meter (m^3).

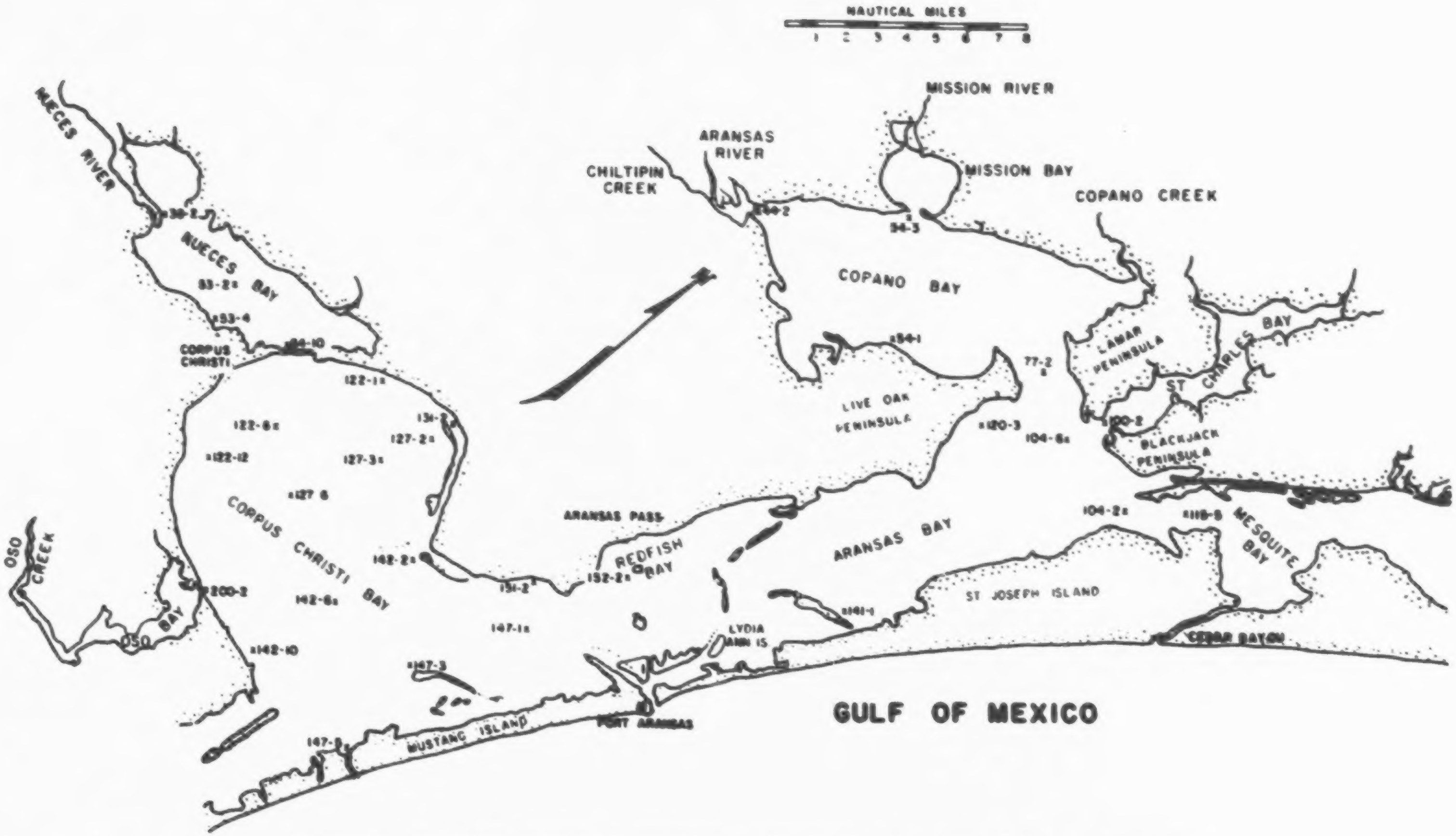
Local rainfall data, which were collected at the Corpus Christi International Airport were obtained from summaries of annual rainfall for this area (United States Department of Commerce 1972, 1973, 1974, 1975). Total inches of rainfall for the 10-day period prior to and including the collecting date, were used for linear correlations with salinity data.

Streamflow data were obtained from the Texas Natural Resources Information System in Austin, Texas for the following gaging stations:08211000, Nueces River near Mathis, Texas; 08211520, Oso Creek at Corpus Christi, Texas; 08189700, Aransas River near Skidmore, Texas; 08189800, Chiltipin Creek at Sinton, Texas; and 08189500, Mission River at Refugio, Texas. These were the most downstream gaging stations nearest the sampling sites. Streamflow was measured in cubic feet/second (cfs). Total inflow for a 10-day period, prior to and including the date of data collection, were used for linear correlations. All linear correlations between streamflow and zooplankton standing crops were calculated using raw data. The critical level for rejection of significance for a linear correlation was $p = 0.05$.

Water temperature, dissolved oxygen, conductivity, and salinity were measured at each station. Salinity was the only hydrographic data used for analysis in this presentation.

RESULTS

The highest recorded rainfall from October 1972 to May 1975 for


NAUTICAL MILES
1 2 3 4 5 6 7 8
NUECES RIVER
39-2
NUECES BAY
53-2
53-4
54-10
CORPUS CHRISTI
122-1
122-6
122-12
131-2
127-2
127-3
127 6
CORPUS CHRISTI BAY
142-2
142-6
200-2
142-10
OSO CREEK
OSO BAY
151-2
147-1
147-3
147-5
MUSTANG ISLAND
PORT ARANSAS
ARANSAS PASS
REDFISH BAY
132-2
LYDIA ANN IS
141-1
ARANSAS BAY
ST JOSEPH ISLAND
CEDAR BAYOU
GULF OF MEXICO
CHILTIPIN CREEK
ARANSAS RIVER
94-2
MISSION RIVER
MISSION BAY
94-3
COPANO CREEK
COPANO BAY
94-1
LIVE OAK PENINSULA
77-2
120-3
104-6
LAMAR PENINSULA
ST CHARLES BAY
100-2
BLACKJACK PENINSULA
104-2
118-5
MESQUITE BAY

NUECES—CORPUS CHRISTI, COPANO—ARANSAS BAY SAMPLING STATIONS the 10-day pre-collection period was 21.6 cm recorded in June 1973 (Figure 2). Lower peaks of 13.2 and 19.3 cm were recorded in September and October 1972, respectively. In June 1974, 6.1 cm of rain occurred and in September 1974, 8.1 cm of rain were recorded.

Salinity ranges and means for each station were: Station 38-2, 0.2-31.6 ppt, $\bar{x} = 12.8$ ppt; Station 200-2, 0.2-35.2 ppt, $\bar{x} = 24.4$ ppt; Station 44-2, 0.0-18.3 ppt, $\bar{x} = 7.7$ ppt; Station 54.3, 0.1-17.1 ppt, $\bar{x} = 7.9$ ppt. Salinity was negatively correlated with local rainfall at Stations 38-2, 200-2, 44-2, and 54-3 ($r = -0.45$, -0.73, -0.53, and -0.51, respectively, $p \leq 0.01$).

Streamflow and salinity patterns for Stations 38-2 and 200-2 are given in Figure 3. Streamflow for the Nueces River (Station 38-2) had its first major increase in June 1973 to 23,960 cfs (670.9 m^3/sec), followed by a decrease to 6,007 cfs (168.2m^3/sec) in July and 4,596 cfs (128.7 m^3/sec) in September. The highest inflow for Station 38.2 was 99,930 cfs (2798.0 m^3/sec) which occurred in October 1973. The salinity decreased to 3.6 ppt in June 1973 and reached a low of 0.4 ppt in October and November 1973. Although the inflow decreased to 2,868 cfs (80.3 m^3/sec) in December 1973 the salinity was still low at 1.3 ppt. Another influx of fresh water was recorded on the Nueces River in August and September 1974 (28,471 cfs (797.2 m^3/sec) and 64,210 cfs (1797.9 m^3/sec), respectively. For August 1974 salinity decreased to 0.4 ppt and in September 1974 salinity was 0.2 ppt. Streamflow had a negative correlation with salinity for Station 38-2 ($r = -0.47$, $p \leq 0.005$).

In June 1973 the inflow for Oso Creek (Station 200-2) increased to 2,944 cfs (82.4 m^3/sec) with a corresponding decrease in salinity to 8.2 ppt. (Figure 3). Streamflow dropped in July and August to 134 cfs (3.8 m^3/sec) and 92 cfs (2.6 m^3/sec), respectively, and salinity increased to 23.3 ppt and 24.2 ppt, respectively. Major inflows of 5,511 cfs (154.3 m^3/sec) with corresponding salinities of 0.2 ppt and 3.6 ppt, occurred in September and October 1973. Although flow increased in June and September 1974 to 905 cfs (25.3 m^3/sec) and 304 cfs (8.3 m^3/sec), respectively, no decrease in salinity was measured. Streamflow was negatively correlated with salinity at Station 200-2 ($r = -0.77$, $p \leq 0.005$).

The Aransas River-Chiltipin Creek drainage (Station 44-2) and the Mission River (Station 54.3) had inflow and salinity patterns similar to each other (Figure 4). Major streamflow increases occurred from June through October 1973, in May and June 1974, and in September 1974. Both Station 44-2 ($r = -0.50$, $p \leq 0.005$) and Station 54.3 ($r = -0.49$, $p \leq 0.005$) had negative correlations between streamflow and salinity.

To determine effects of freshwater inflow on zooplankton populations, species were first categorized to be estuarine or freshwater species. A list of the dominant zooplankton is given in Table 1. Those species with an asterisk are considered to be freshwater organisms.

The effect of streamflow on standing crops (total number of individuals/m^3) of estuarine and freshwater zooplankton at Station 38-2 is shown in Figure 5. Standing crops of

Table 1. List of Dominant Estuarine and Freshwater Zooplankton

Phylum Protozoa
Class Mastigophora
Order Dinoflagellata
Noctiluca scintillans

Phylum Rotifera
Rotifera sp. A
Brachionus plicatilis
*Brachionus quadradentata**
Lecane sp.*
*Platyias quadricornis**

Phylum Annelida
Class Polychaeta
Polychaete larvae

Phylum Mollusca
Class Gastropoda
Gastropod larvae

Class Pelecypoda
Pelecypod larvae

Phylum Arthropoda
Class Crustacea
Order Diplostraca
Cladocerans (immature)*

Family Sididae
Diaphanosoma sp.*
Family Daphnidae
Ceriodaphnia sp.*
Daphnia sp. *
Moina sp. *
Simocephalus sp.*
Family Bosminidae
Bosmina sp.*
Family Macrothricidae
Illyocrytis spinifer
Macrothrix sp.*

Order Calanoida
Family Diaptomidae
Diaptomus sp.*
Pseudodiaptomus coronatus
Family Paracalanidae
Paracalanus crassirostris

Table 1 Cont.'d

- Family Pontellidae
  - *Labidocera aestiva*
- Family Acartiidae
  - *Acartia tonsa*
- Family Unidentified
  - Copepod nauplii

Order Harpacticoida
- Family Laophontidae
  - *Onychocamptus mohammed**
- Family Cletedidae
  - *Cletocamptus albuquerquensis**
  - *Cletocamptus dietersi**

Order Cyclopoida
- Family Oithonidae
  - Oithona spp.
- Family Cyclopidae
  - Cyclopoid copepodids*
  - *Cyclops* sp.*
  - *Eucyclops agilis**
  - *Eucyclops speratus**
  - *Macrocyclops albidus**
  - *Mesocyclops edax**
  - *Microcyclops* sp.*

*Denotes freshwater species

460

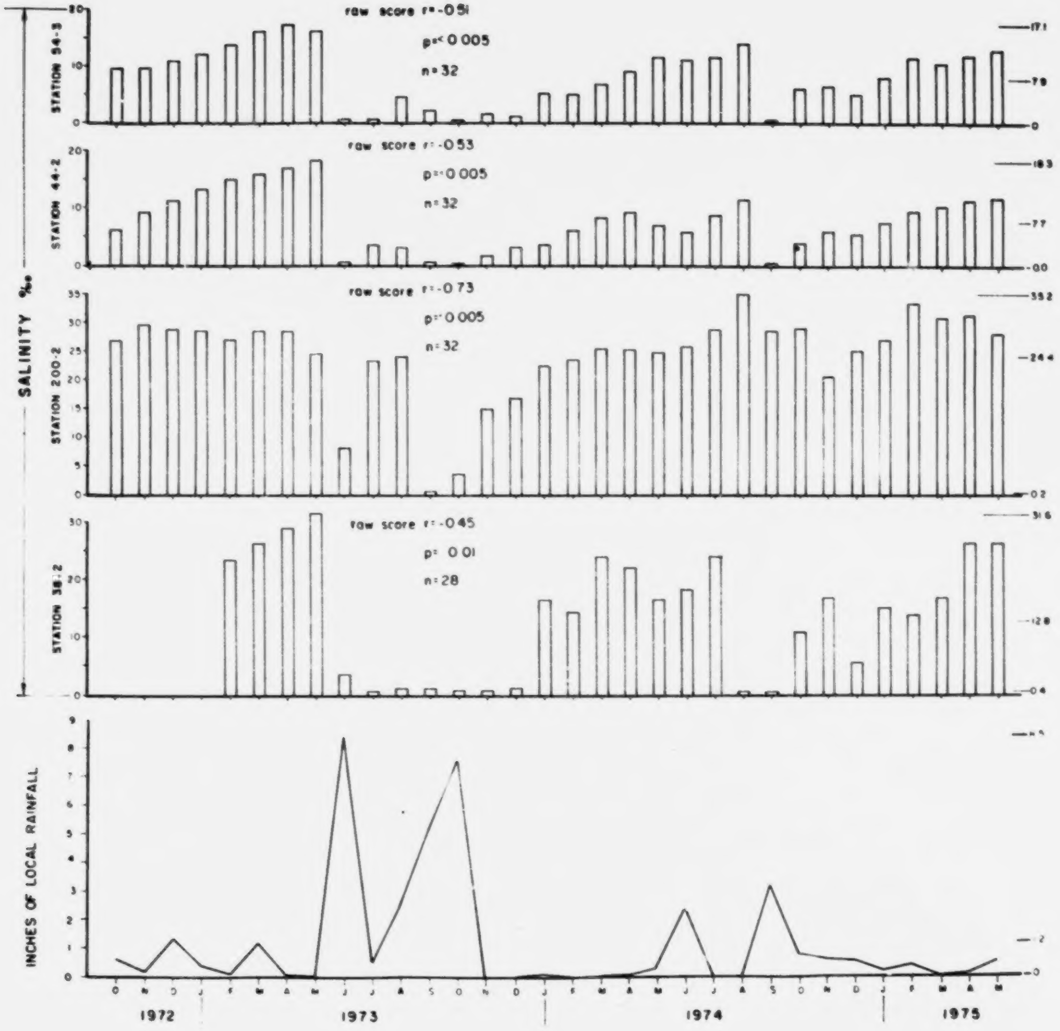


Figure 2. Salinity by station and local rainfall for 10-day period prior to and including data collection, October 1972 - May 1975.

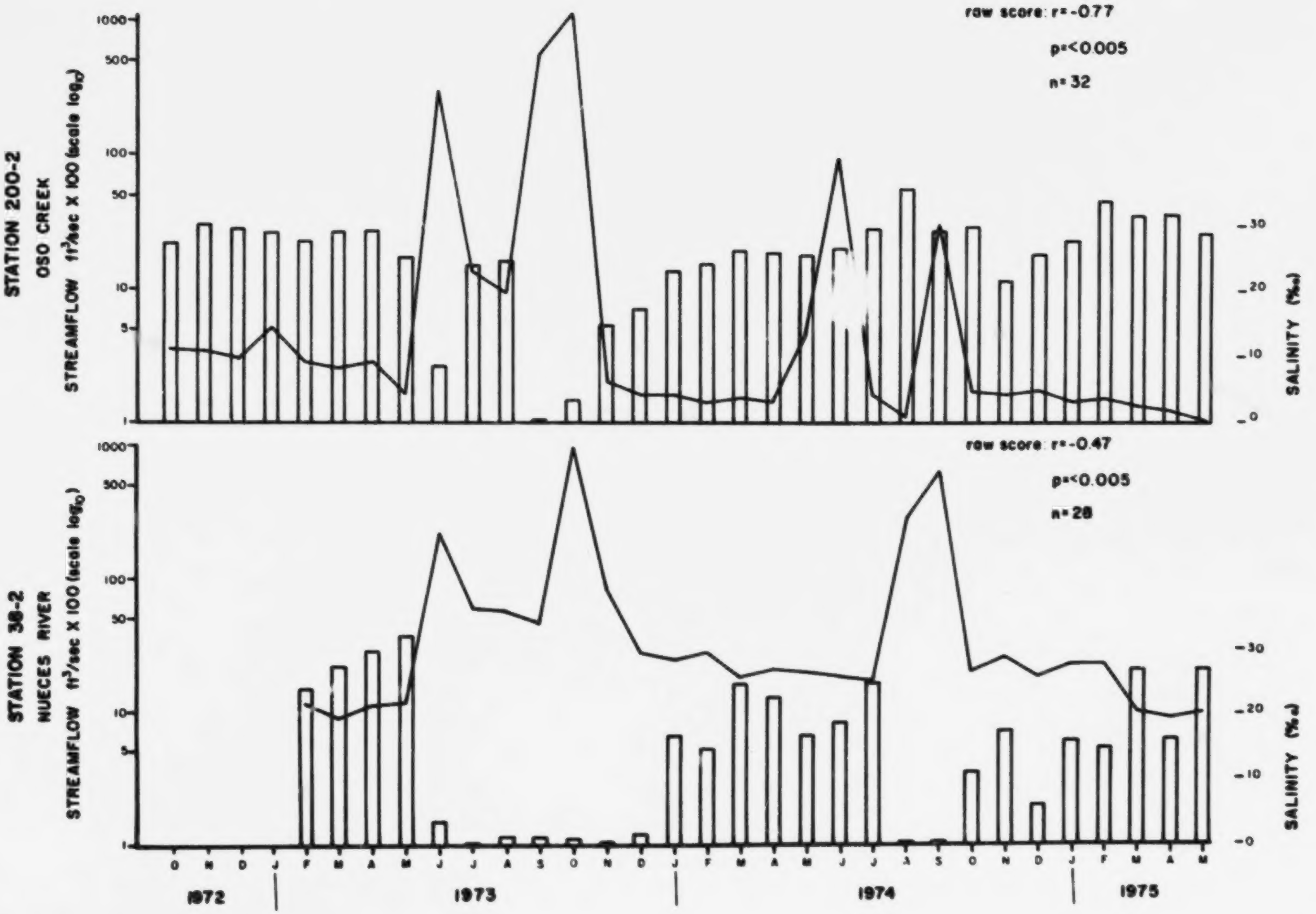


Figure 3. Streamflow and salinity profiles for Station 38-2 and 200-2, October 1974 - May 1973.

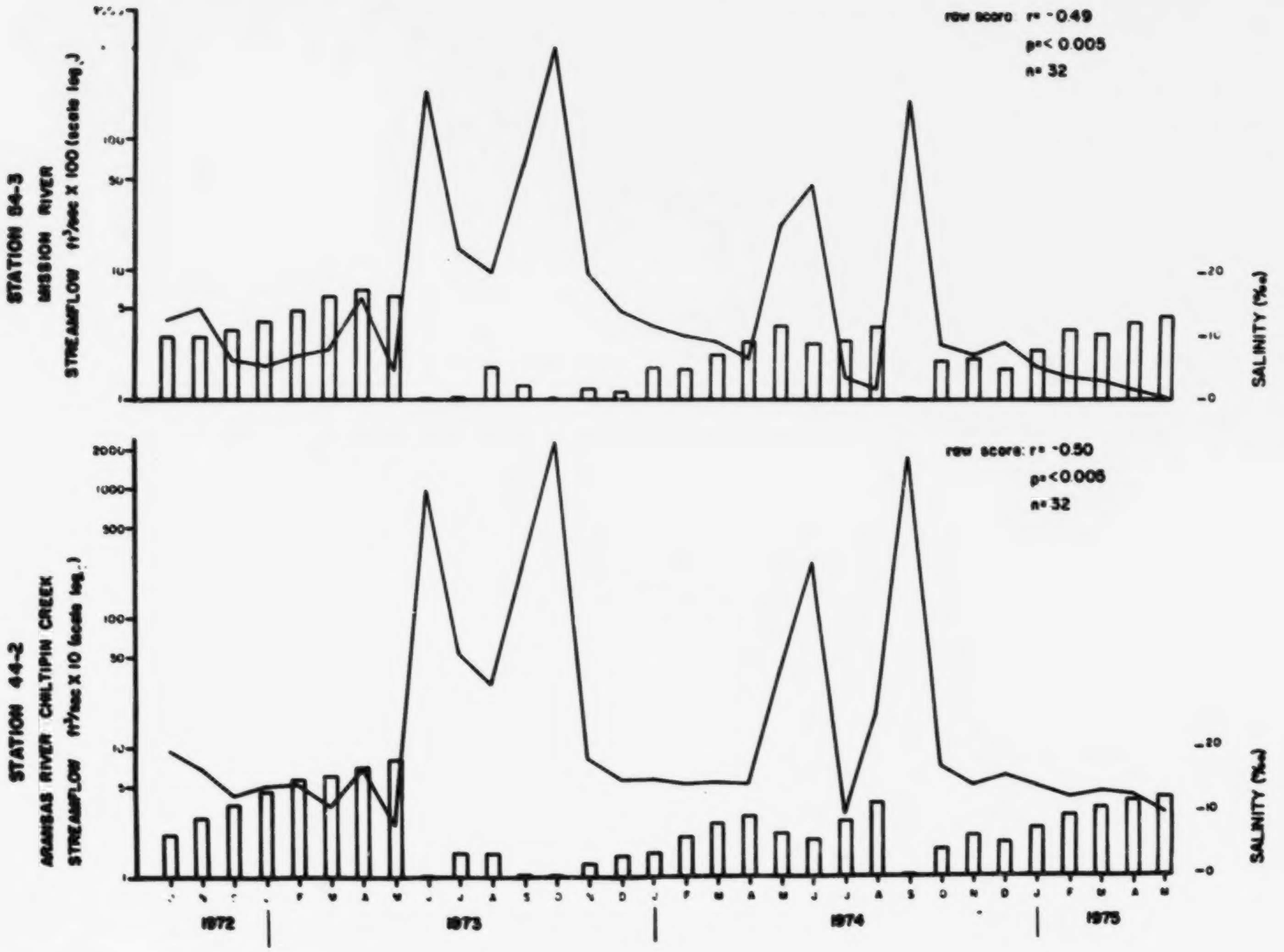


Figure 4. Streamflow and salinity profiles for Stations 44-2 and 54-3, October 1972 - May 1975.

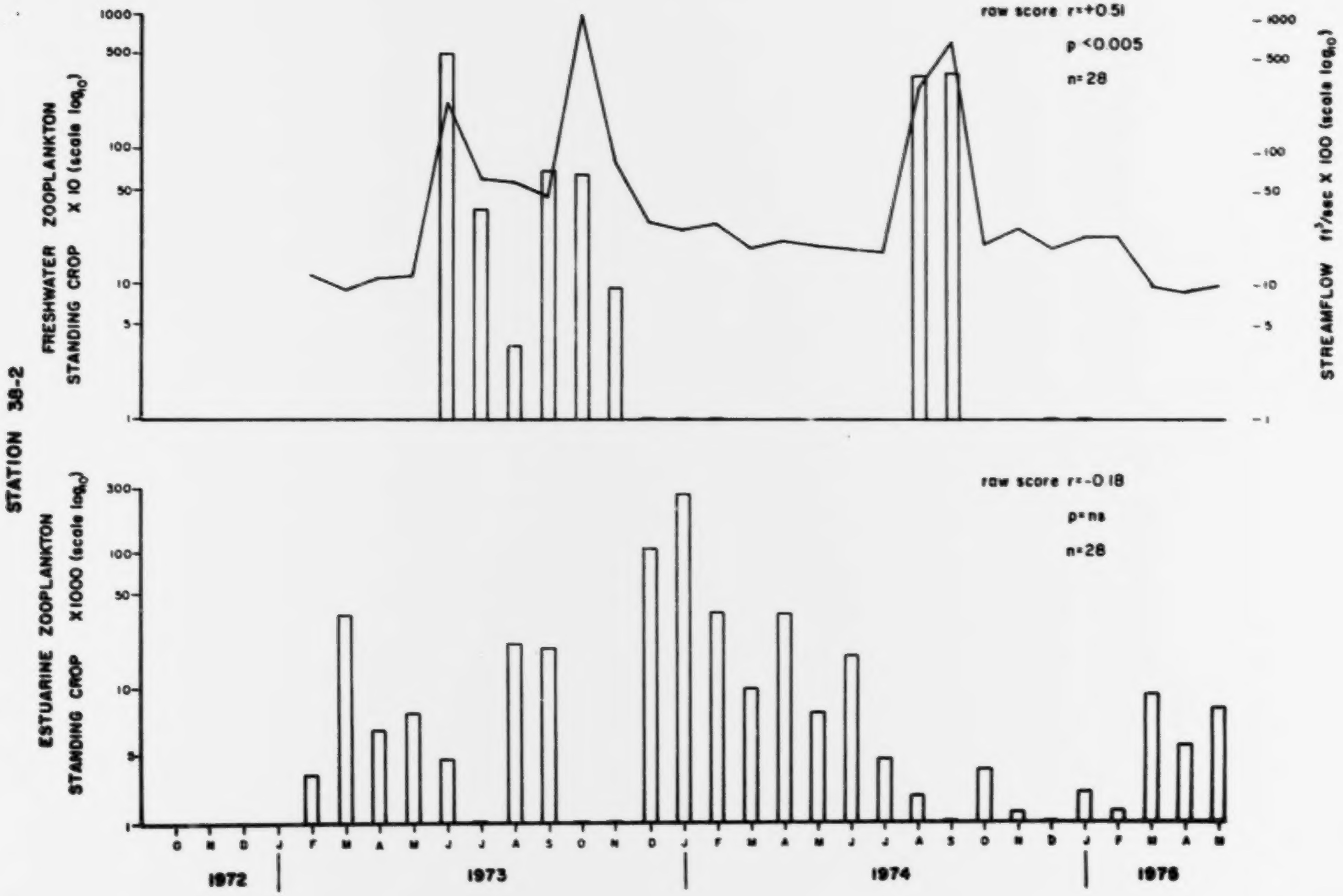


Figure 5. Estuarine and freshwater zooplankton standing crop (total individuals/m^3) and streamflow profiles for Station 38-2, October 1972 - May 1975.

freshwater species had a positive correlation with streamflow ($r = +0.051$, $p \leq 0.005$) while the correlation between standing crops of estuarine species and streamflow was not significant. Freshwater species first occurred at Station 38-2 in June 1973 (5,168/m^3). The highest numbers of freshwater species were associated with a period of extensive inflow from June through November 1973. During this period numbers of estuarine species were lowest in July (94/m^3), October (65/m^3), and November 1973 (247/m^3). Remnants of freshwater populations were evident in December 1973 (1/m^3), January 1974 (0.3/m^3), February 1974 (7/m^3). Freshwater species increased in August 1974 (3,679/m^3) and September 1974 (3,850/m^3) with increased inflows. Low numbers of freshwater species were found in December 1974 (8/m^3) and January 1975 (1/m^3). Decreased estuarine species occurred in July 1973 (94/m^3), October 1973 (65/m^3), and November 1973 (247/m^3), and September 1974 (185/m^3) during freshwater inflow.

At Station 200-2 standing crops of freshwater zooplankton were positively correlated with streamflow ($r = +0.84$, $p \leq 0.005$) while estuarine species were not (Figure 6). The greatest effect of streamflow increases on estuarine species standing crop was in September 1973 when numbers dropped to 818/m^3. In June 1973 (370/m^3), September 1973 (1116/m^3), and October 1973 (638/m^3) incursions of freshwater zooplankton occurred with increased streamflow. The only other freshwater species observed were in May (1/m^3) and June 1974 (1.5/m^3).

The effects of streamflow on standing crops of estuarine and freshwater zooplankton at Stations 44-2 and 54-3 in Copano Bay were similar (Figures 7 and 8). Positive correlations for streamflow versus freshwater species occurred at Station 44-2 ($r = +0.49$, $p \leq 0.005$) and Station 54-3 ($r = +0.64$, $p \leq 0.005$). Freshwater species at Station 44-2 were most abundant in June 1973 (385/m^3), July 1973 (42/m^3), September 1973 (3,045/m^3), and October 1973 (724/m^3), and in September 1974 (1,708/m^3) during which times streamflow was greatest. Only low numbers of freshwater zooplankton were associated with increased streamflow in May 1974 (1/m^3) and June 1974 (21/m^3).

At Station 44-2 the correlation between streamflow and estuarine zooplankton standing crops was not significant. Increased inflows at Station 44-2 resulted in low standing crops of estuarine zooplankton in June 1973 (177/m^3), September 1973 (175/m^3), and October 1973 (535/m^3), and in September 1974 (104/m^3) and October 1974 (388/m^3).

Incursions of freshwater species at Station 54-3 occurred in June (416/m^3), July (93/m^3), and October 1973 (375/m^3), and in September 1974 (1,319/m^3). A few freshwater organisms were found in November 1973 (8/m^3) and February 1974 (3/m^3). The correlation of streamflow and standing crops of estuarine species at Station 54-3 was not significant. Estuarine standing crops decreased in October 1973 (100/m^3) and in September 1974 (176/m^3).

Acartia tonsa, a ubiquitous calanoid occurred at salinities ranging from 0.04 ppt at Station 44-2 in October 1973 to 35.2 ppt at Station 200-2 in August 1974. Linear correlations of total numbers/m^3 of A. tonsa with streamflow were calculated for each station (Figure 9). With the exception of Station 44-2,

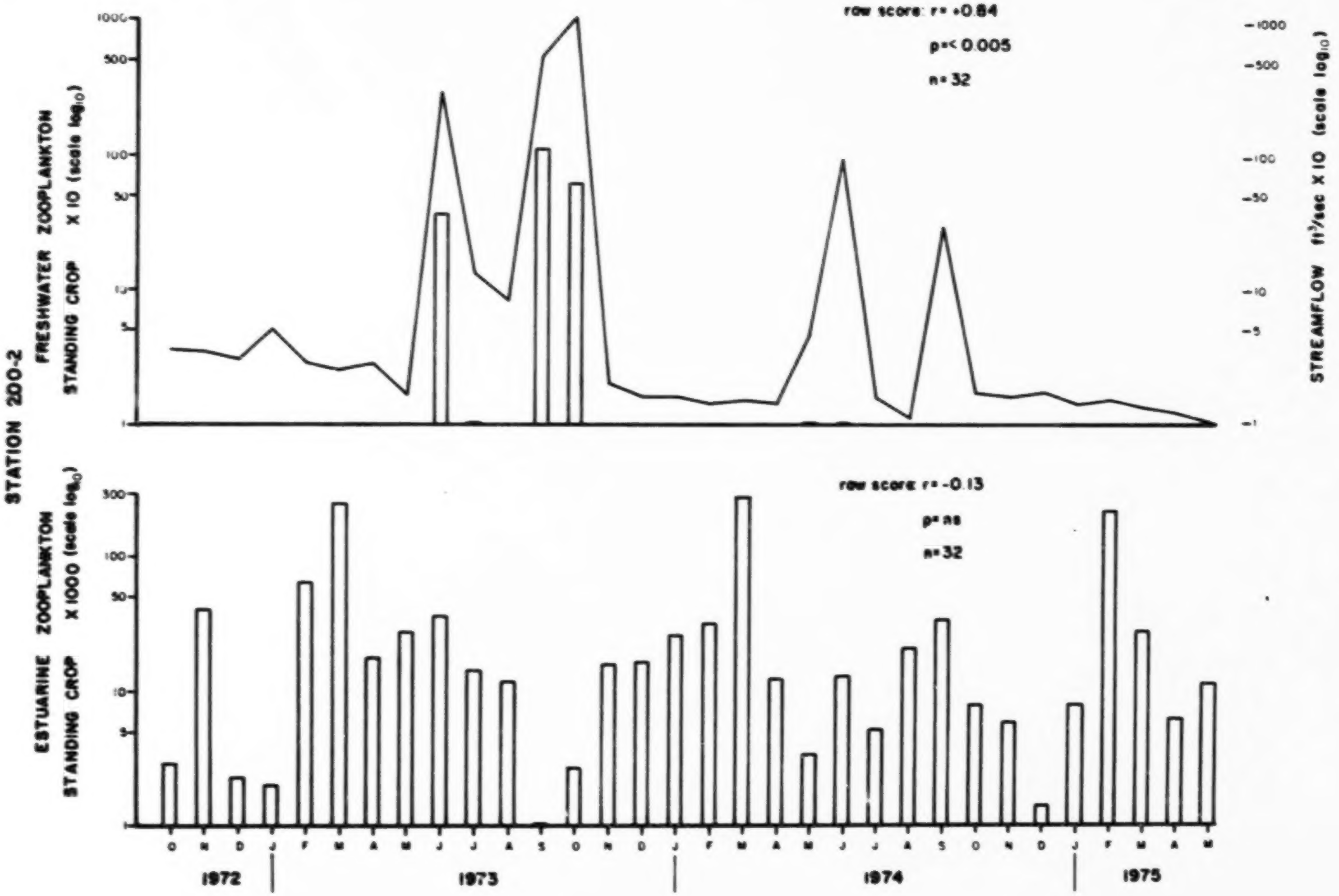


Figure 6. Estuarine and freshwater zooplankton standing crop (total individuals/m^3) and streamflow profiles for Station 200-2, October 1972 - May 1975.

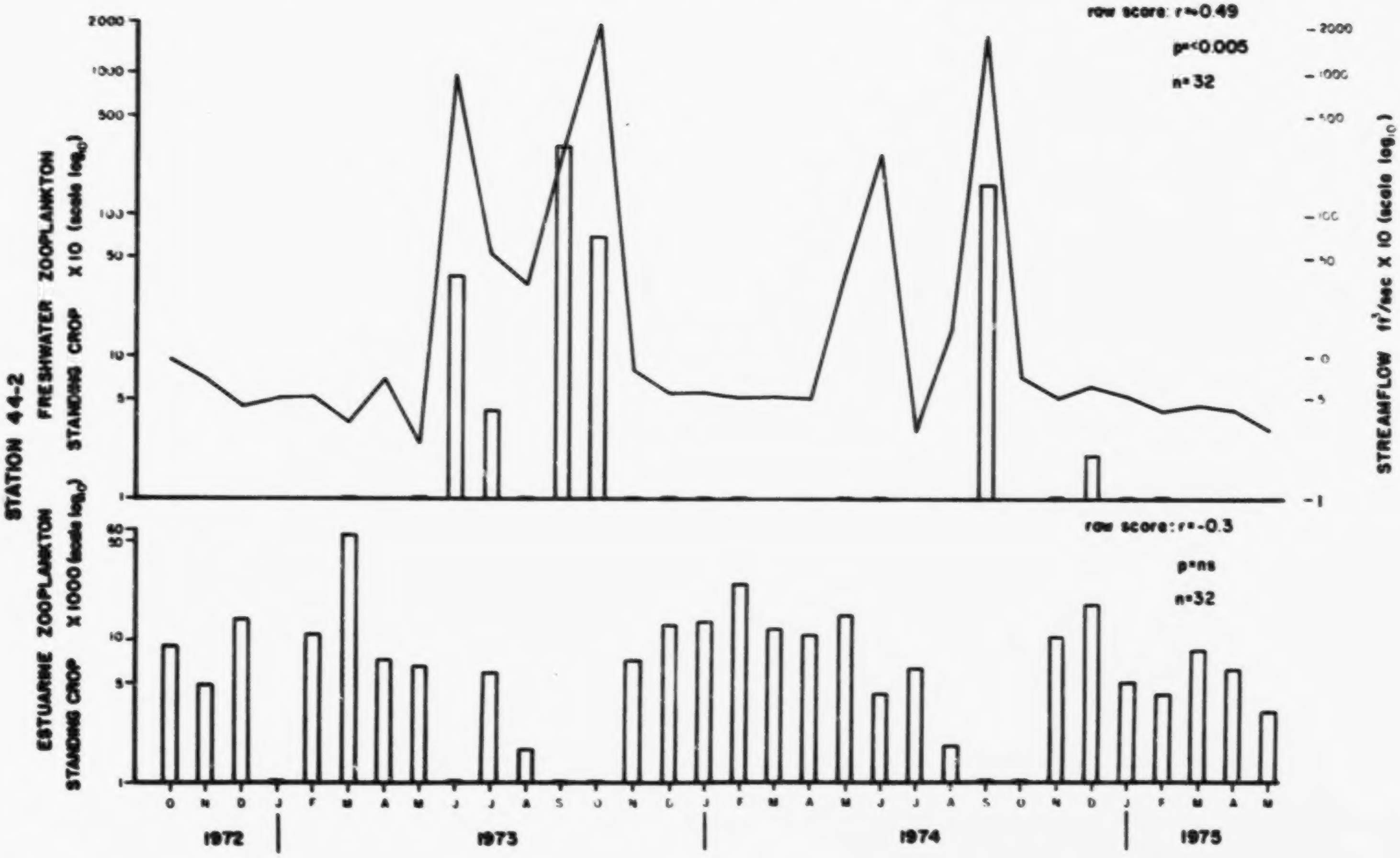


Figure 7. Estuarine and freshwater zooplankton standing crop (total individuals/m^3) and streamflow profiles for Station 44-2, October 1972 - May 1975.

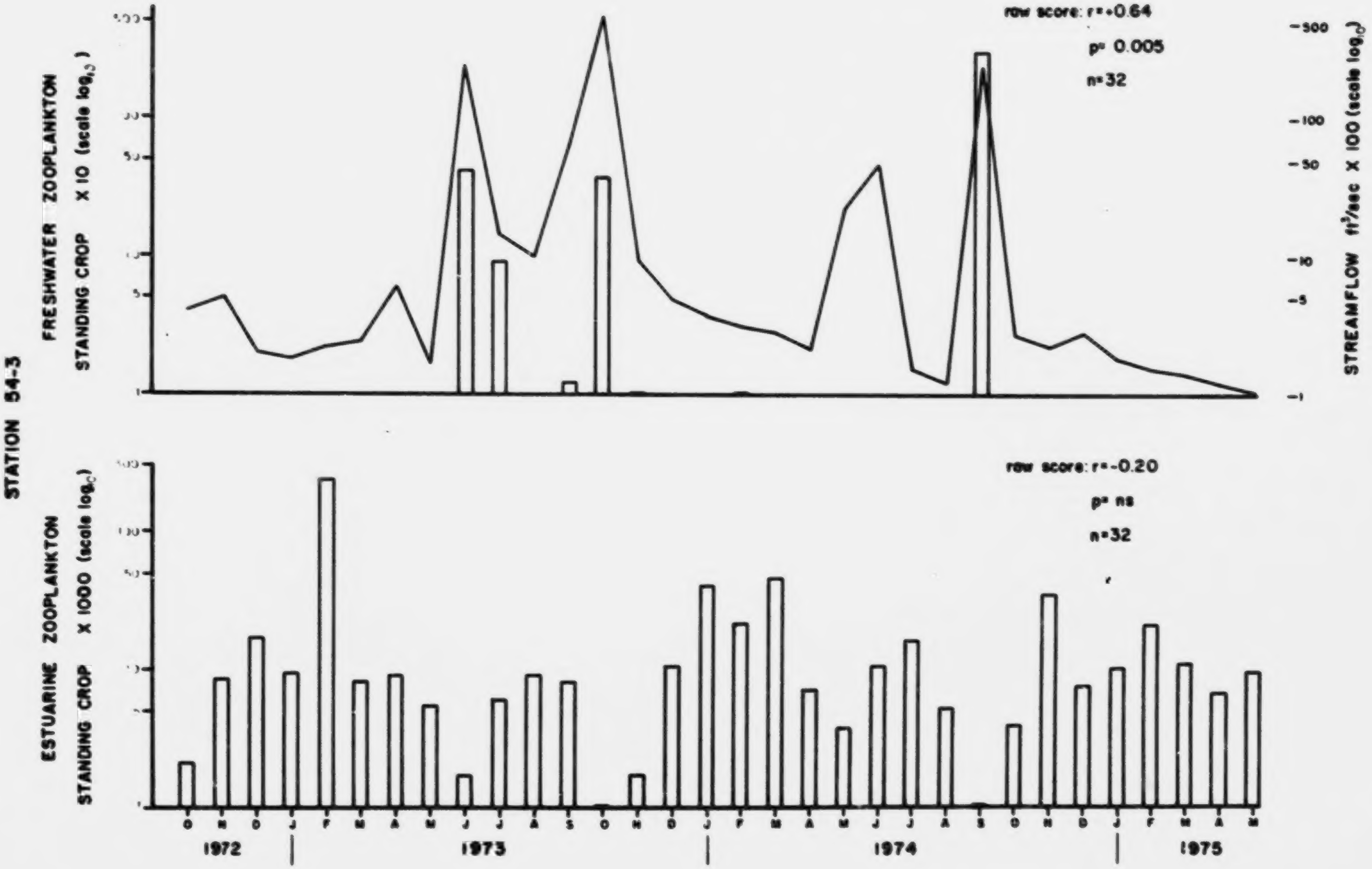


Figure 8. Estuarine and freshwater zooplankton standing crops (total individuals/m^3) and streamflow profiles for Station 54-3, October 1972 - May 1975.

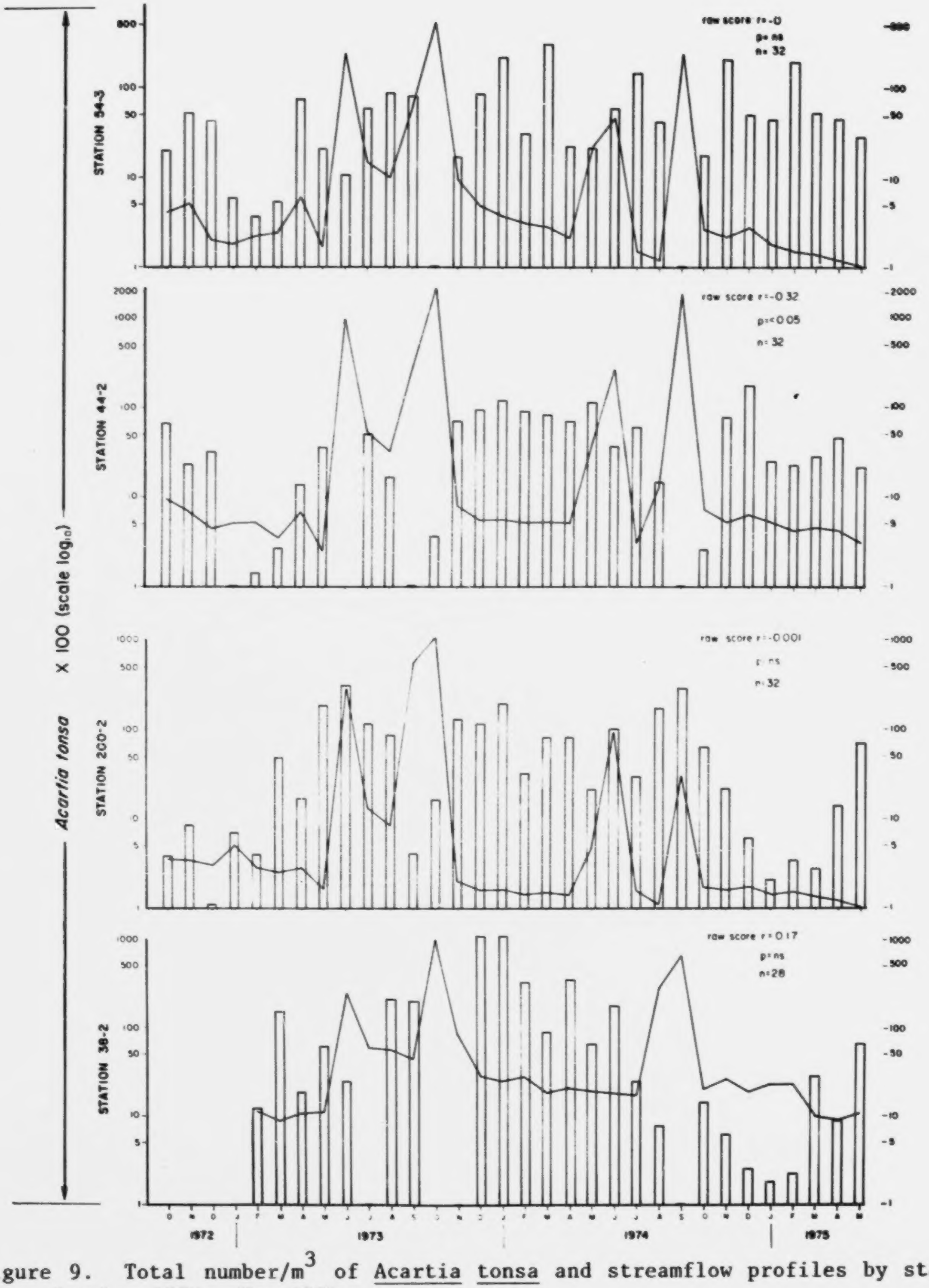


Figure 9. Total number/m^3 of Acartia tonsa and streamflow profiles by station, October 1972 - May 1975.

where numbers/m^3 of *A. tonsa* were negatively correlated with streamflow ($r = -0.32$, $p \leq 0.05$), correlations at Stations 38-2, 200-2, and 54-3 were not significant. *A. tonsa* was collected every month at each station except in October 1973 at Station 44-2. The lowest numbers of *A. tonsa* were associated with high peaks of freshwater inflow at Stations 38-2 in July 1973 (30/m^3), October 1973 (0/m^3), and September 1974 (21/m^3); at Station 44-2 in June 1973 (0/m^3), September 1973 (90/m^3), and September 1974 (29/m^3); and at Station 54-3 in October 1974 (25/m^3) and September 1974 (67/m^3). No obvious declines in numbers of *A. tonsa* were seen in association with freshwater inflow at Station 200-2. Following incursions of fresh water, populations of *A. tonsa* showed rapid recovery, usually to greater numbers than before flooding even though salinities may have remained low.

DISCUSSION

Although local rainfall was significant and negatively correlated with salinity at Stations 38-2, 200-2, 44-2, and 54-3 a stronger correlation (or higher absolute value of r) was obtained when streamflow was correlated with salinity at each station. Fluctuations in salinity resulting from freshwater inflow to the estuaries are dependent not only on local rainfall but also on precipitation and run-off from inland areas. The higher overall salinities recorded during this study in the Nueces-Corpus Christi Bay system indicate that this area is affected by tidal incursions of higher salinity Gulf water more than the Copano-Aransas area. While salinities in the upper Nueces Bay (Station 38-2) tend to remain low for an extended period following freshwater inflows, the area near the mouth of Oso Bay (Station 200-2) shows a rapid return to higher salinity following freshwater inflows, due to tidal flushing with higher salinity gulf water. The remoteness of Copano Stations 44-2 and 54-3 from the Aransas Pass Inlet results in a long flushing time and very little mixing with gulf water, accounting for the overall lower salinities in this area.

The initial effects of increased freshwater inflow near the observation points of the study result in the physical displacement of estuarine water with freshwater. Freshwater zooplankton populations replace estuarine zooplankton for short periods until mixing with estuarine water raises salinities to levels which allow estuarine species to recover.

The euryhaline copepod, *A. tonsa*, the most dominant calanoid copepod throughout this study and other studies along the Texas coast (Gilmore et al. 1976; Holland et al. 1974, 1975; Matthews et al. 1975; McAden 1977; Rennie 1975; Srithavatch 1973; Texas Dept. of Water Resources 1980), is a very important link in the estuarine food chain. *A. tonsa*, after initially being displaced by freshwater species during high inflow, is very tolerant to low salinities and is able to repopulate a low salinity area very quickly. It is speculated that the success of large populations of *A. tonsa* following peak inflows can probably be attributed to influx of nutrients, food, and a decrease in higher salinity predators.

CONCLUSIONS AND RECOMMENDATIONS

1. Salinity fluctuations in the study area were negatively correlated

with local rainfall. Stronger negative correlations were observed, however, for salinity with streamflow.

2. Major freshwater incursions physically flush out estuarine zooplankton populations and replace them with freshwater species.

3. Increased salinities even as low as 1.0 ppt to 3.0 ppt results in a rapid return of estuarine species, especially the euryhaline copepod, *Acartia tonsa*.

4. Periodic high influxes of freshwater are potentially important sources of nutrients to the estuarine system.

5. Concentrated studies at point sources of freshwater inflow to the estuaries to monitor biological, physical and chemical parameters should continue to be conducted to establish the most important variables controlling estuarine communities in relation to freshwater inflow.

REFERENCES

Anderson, A.A. Marine resources of the Corpus Christi area. Research Monograph No. 21, Austin, TX: Bureau of Business Research, Univ. of Texas, 49pp. 1980.

Collier, A., and Hedgepeth, J.W. An introduction to the hydrography of tidal waters of Texas. Publ. Inst. Mars. Sci. Univ. Tex. 1(2):121-194; 1950.

Gilmore, G. et al. A study of the effects of freshwater on the plankton, benthos, and nekton assemblages of the Lavaca Bay system, Texas. Texas Parks and Wildlife Rep. to Texas Water Development Board; 1976: 113p.

Gunter, G. Studies on marine fishes of Texas. Publ. Inst. Mar. Sci., Univ. Tex. 1(1):1-190; 1945.

Holland, J.S., Maciolek, N.J.; Kalke, D.; Oppenheimer, C.H. A benthos and plankton study of the Corpus Christi, Copano and Aransas Bay systems, II. Report on the data collected during the period July 1973 to April 1974. Unpublished second annual report to the Texas Water Development Board, Port Aransas, TX: Univ. of Texas Mar. Sci. Inst. 1974; 212p.

Holland, J.S., Maciolek, N.J.; Kalke, D.; Mullins, H.L.; Oppenheimer, C.H. A benthos and plankton study of the Corpus Christi, Copano and Aransas Bay Systems. III. Report on data collected during the period July 1974 to May 1975 and summary of the three year project. Unpublished final report to the Texas Water Development Board. Port Aransas, TX: Univ. of Texas Mar. Sci. Inst. 1975; 174p.

Hood, D.W. A hydrographic and chemical survey of Corpus Christi Bay and connecting water bodies. Progress Rep. Project 40, Texas A&M Research Fdn. 1952; 42p.

Matthews, G.A. et al. A plankton and benthos survey of the San Antonio Bay system, March 1972 to July 1974. Texas Parks and Wildl. Dept., Tech. Rep. to the Texas Water Development Board; 1975.

McAden, D.C. Species composition, distribution and abundance of zooplankton (including ichthyoplankton) in the intake and discharge canals of a stream-electric generating station located on Galveston Bay, Texas. College

Station: Texas A&M Univ., 1977; 308p. Thesis.

Parker, R.H. Macroinvertebrate assemblages of central Texas coastal bays and Laguna Madre. Bull. Am. Assoc. Petrol. Geol. 43(9): 2100-2188; 1959.

Rennie, T.H. Zooplankton studies in the Cox Bay, Texas area before and during early operation of and electric power plant. College Station: Texas A&M Univ., 1975; 381p. Dissertation.

Srithavatch, K. The species diversity and abundance of the zooplankton of the Matagorda Bay system. Kingsville, TX: Texas A&I Univ. 1973; 104p. Thesis.

Texas Department of Water Resources. Lavaca-Tres Palacios estuary: a study of the influence of freshwater inflows. Texas Dept. Water Res. LP-106:VII/II-VII/22; 1980.

Texas Water Development Board. The Texas water plan. Austin, TX: 1968.

United States Department of Commerce. Local climatological data, annual summary with comparative data, Corpus Christi, Texas. National Oceanic and Atmospheric Administration, Environmental Data Service. 1972.

United States Department of Commerce. Local climatological data, annual summary with comparative data, Corpus Christi, Texas. National Oceanic and Atmospheric Administration, Environmental Data Service; 1973.

United States Department of Commerce. Local climatological data, annual summary with comparative data, Corpus Christi, Texas. National Oceanic and Atmospheric Administration, Environmental Data Service; 1974.

United States Department of Commerce. Local climatological data, annual summary with comparative data, Corpus Christi, Texas. National Oceanic and Atmospheric Administration, Environmental Data Service; 1975.

NUTRIENT FLUX BETWEEN THE NUECES DELTAIC MARSH AND THE NUECES ESTUARY ON THE TEXAS GULF COAST

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ABSTRACT

Movements of carbon, nitrogen, and phosphorus in the surface waters between a tidal marsh and the Nueces estuary, Nueces County, Texas, were studied over an 8-month period. Seasonal patterns in nutrient flux (where flux = flow x nutrient concentration) were evident throughout the study period. Net fluxes of virtually all nutrient parameters were directed out of the marsh during the fall and winter, but were directed into the marsh during the spring. Combined net input of C, N, and P in the spring and summer ranged from 33 to 571 kg/hr. Tidal fluctuations in the Nueces estuary are normally low (0-60 cm). Based on the study period the Nueces marsh acts as a sink for those nutrients transported by tides.

INTRODUCTION

Over the years there has been a great deal of information gathered on the relationship between an estuary and its associated marshes. Several processes such as nutrient exchange and transport, detrital processing, primary production, fisheries dynamics and estuarine hydrology have been studied. Until recently most of these studies have been born of purely academic curiosity. But now the recent trend of reduction of freshwater inflows into these estuaries for domestic and industrial use has resulted in studies designed to assess impacts of such actions on the estuarine system as well as to help in the development of overall management strategies for these areas.

One such study was recently performed in the Nueces-Corpus Christi Bay System located on the lower Texas coast in order to provide information needed to establish a management scheme for freshwater releases from an impoundment structure being built on the Nueces River in south central Texas. Part of this study involved gathering data on nutrient flux in the Nueces marsh, adjacent to the Nueces River, in an effort to better understand the role which the marsh plays in processing nutrients (carbon, nitrogen, and phosphorus) that are brought into the system.

This paper is a presentation of results derived from field data collected during the period of October 1978 to June 1979. Development of this data and information from various other sources is presented in "Freshwater Needs of Fish and Wildlife Resources of Nueces-Corpus Christi Bay Area, Texas" (Henley and Rauschuber 1981).

MATERIALS AND METHODS

STUDY AREA

The selected study site, the Nueces deltaic marsh, lies in a broad basin flanked by bluffs on each side approximately 5-10 miles north and west of Corpus Christi, Texas (Figures 1 and 2). Flooding and drainage of the marsh occurs mainly through the Rincon Bayou, although two smaller channels, one dredged and one natural, also serve this function. The marsh is crossed by a few old shell roads, used in earlier years during oil and gas drilling activities, and by a railroad right-of-way. The marsh is bounded on the north and east by areas of considerable agricultural and pastoral activity and on the south by a heavy industrial zone along Corpus Christi harbor (catering mainly to shipping and oil storage).

The areal extent of the marsh has been estimated at 12,300 acres (4,990 ha) and is composed of algal-covered mud flats and emergent marsh vegetation (Benton et al. 1975). Dominant vegetation found in the marsh is generally characteristic of vegetation found in other Texas estuarine systems. Dominant species are Batis maritima, Salicornia virginica, Spartina spartinae, Monanthocloe littoralis, Borrichia frutescens, and Distichlis spicata. Annual net above-ground primary production for the 12,330 acres of marsh has been estimated at 92.4 million pounds (dry weight) per year (42,000 metric tons/year) in previous studies (Espey, Huston, and Associates 1977). Most of this production is contributed by Borrichia frutescens and Spartina spartinae, as determined in our concurrent studies of marsh primary production. Mean annual tidal amplitudes in the marsh normally range from 0 to 24 inches (0 to 60 cm) and salinities usually vary from 7 to 25 ppt.

MEASUREMENT OF WATER EXCHANGE AND SAMPLING

Flow rates into and out of the Nueces deltaic marsh were measured during the period February 1979 to June 1979. Flow rates for October, November, and December of 1978 were not measured dirctly but were estimated using regression analysis of historical rainfall and tide flow data generated by the United States Geological Survey in Corpus Christi, Texas.

Water samples were taken at mid-depth in the Rincon Bayou using a 4-liter Van Dorn water sampler and immediately placed on ice for transport to the laboratory. Triplicate 1-liter water samples were taken over a 24-hour tide cycle during each sampling trip. Normally there were 4 cycling events during a tide cycle: high slack tide, mean high tide, low slack tide and mean low tide. Each cycle usually lasted 2 to 8 hours. Tide cycle times for the Gulf of

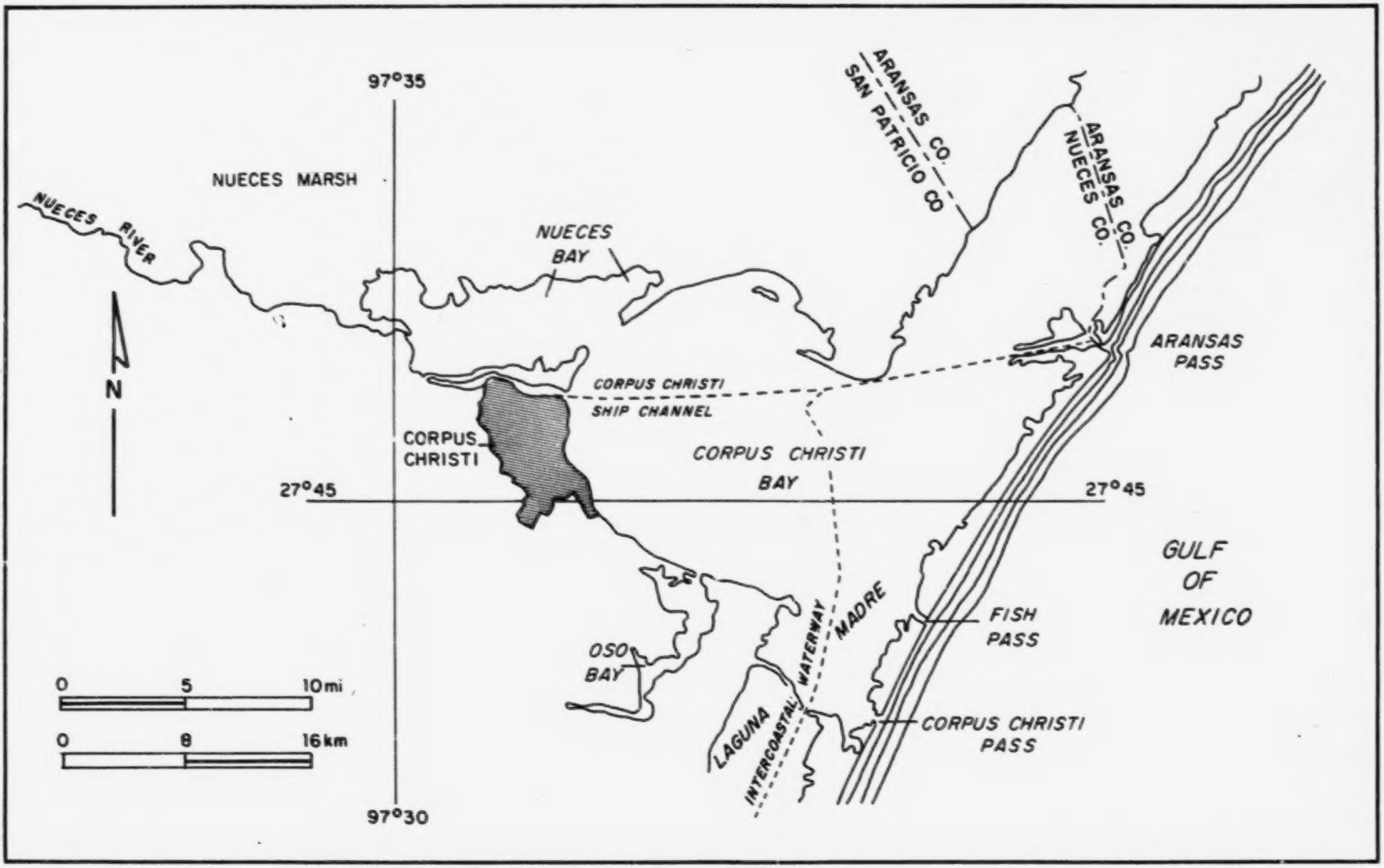
97°35
NUECES MARSH
NUECES RIVER
NUECES BAY
ARANSAS CO.
SAN PATRICIO CO
ARANSAS CO.
NUECES CO.
ARANSAS PASS
N
CORPUS CHRISTI SHIP CHANNEL
CORPUS CHRISTI
CORPUS CHRISTI BAY
27°45
27°45
GULF OF MEXICO
MADRE
FISH PASS
OSO BAY
LAGUNA
INTERCOASTAL WATERWAY
CORPUS CHRISTI PASS
0
5
10mi
0
8
16km
97°30

Figure 1. The geographical location of the Nueces marsh and its relationship to the Nueces-Corpus Christi Bay system.

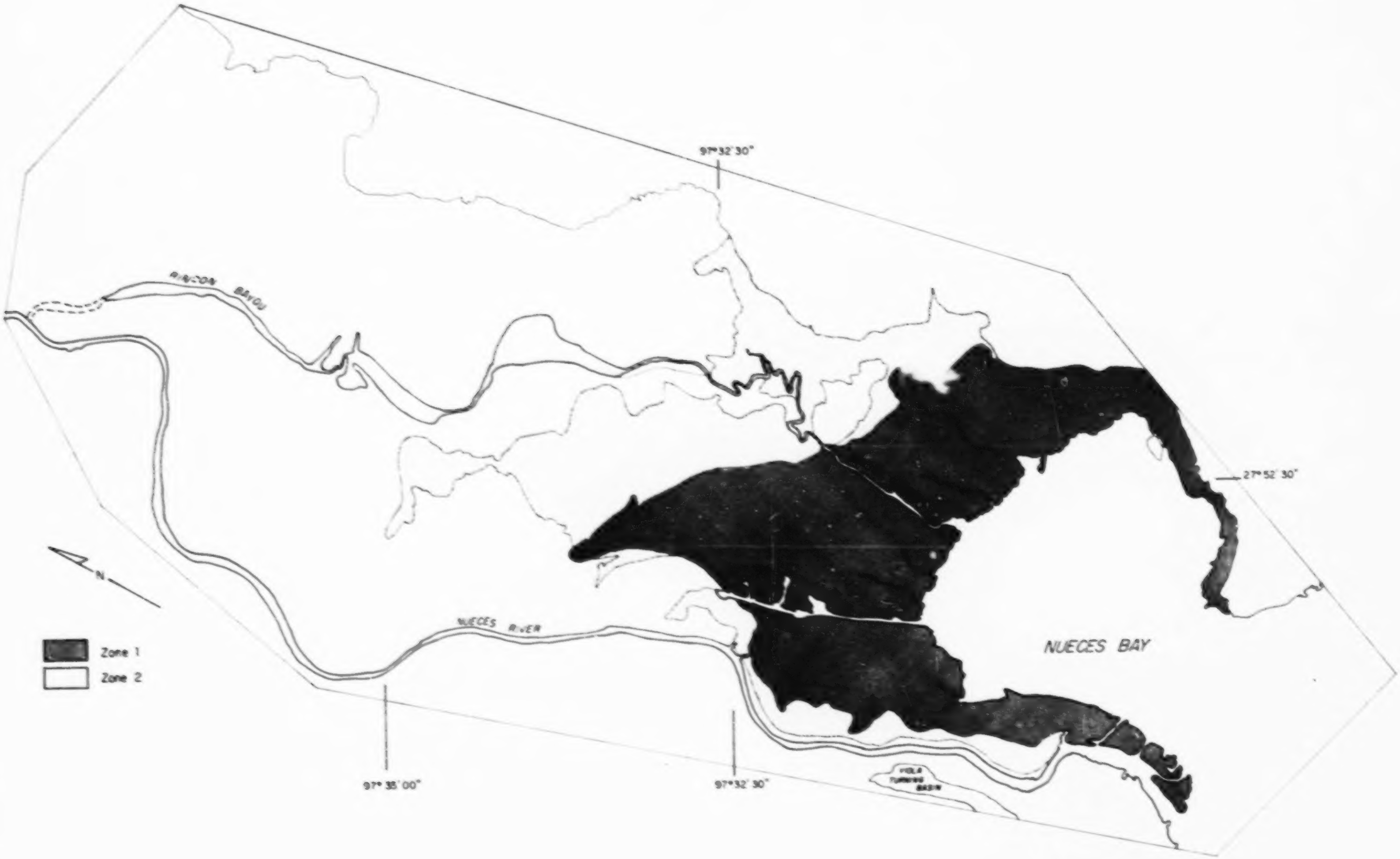
97°32'30"
RINCON BAYOU
27°52'30"
N
NUECES RIVER
Zone 1
Zone 2
NUECES BAY
97°35'00"
97°32'30"
VIOLA TURNING BASIN

Figure 2. An enlarged map of the Nueces marsh showing zones of tidal inundation. Zone 1 depicts the area of the marsh most susceptible to tidal inundation and Zone 2 shows areas that are affected by flooding and extremely high tides. Dotted lines represent the area of the levee through which flood waters pass into the marsh during high river flows.

Mexico were obtained from the National Weather Service prior to sampling and then adjusted to compensate for the distance between the marsh and the gulf. In an effort to consolidate the data for analysis the mean and slack tides for each tide cycle were combined. These events were then designated as flood and ebb tides. Exchanges of water between the Nueces deltaic marsh and bay were estimated by determining flow rates past a sampling station. A measured distance of 100 ft (30.5 m) was laid out along the bank of the Rincon Bayou near its mouth. A weighted (partially submerged) float was then released in midstream and allowed to move with tidal flows. Elapsed time between start and finish yielded the flow rate in m/sec. To determine flow volumes, a cross-sectional map of the bayou was made using a sounding line and tide staff gauge (Figure 3). Individual measurements of velocity were multiplied by the cross-sectional area represented by each respective sampling point to estimate volumes of flow. Velocity measurements were replicated to ensure reliability.

ANALYTICAL METHODS AND EXCHANGE OF MATERIALS

Total organic carbon and inorganic carbon measurements were made using a Dohrmann Model DC-50 organic carbon analyzer modified to measure inorganic carbon. Particulate organic carbon was determined using the method described by Menzel and Vaccaro (1964) and the Dohrmann DC-50 organic carbon analyzer. Total phosphorus and ortho-phosphorus concentrations were determined using the oxidative and spectrophometric methods outlined in Standard Methods (APHA 1975). Nitrate, nitrite, and organic nitrogen forms were determined using methods outlined in Strickland and Parsons (1965) and Standard Methods (APHA 1975). A Beckman Model 25 UV-Vis Spectrophotometer was used in the final analysis of nitrogen and phosphorus forms. Ammonia concentrations were determined using and Orion ammonia probe and Model 901 Orion microprocessor. The detection limits of the probe ranged from 0.02 x 10^4 to 1.7 x 10^4 mg/l free ammonia.

Exchanges of materials on each sampling date were calculated by multiplying the mean concentrations of replicate samples by the estimated flow volume for each tide stage in a 24-hour tidal cycle.

Total exchanges of nutrients between the marsh and the estuary were determined from the difference in quantities of materials entering (flood tides) and leaving (ebb tides) the Rincon Bayou.

RESULTS

Flows in and out of the marsh are for the most part attributable to tidal action, and to a lesser extent wind seiche. Flow rates varied seasonally with highest rates occurring in the spring (8.61 m^3/sec in April flood tide) and the lowest occurring in the late fall (0.59 m^3/sec in November flood tide). During the course of the study no major weather events such as hurricanes or sustained flooding occurred. Spills from the Nueces River into the upper marsh occurred only once during the study period. This event was a brief spill, which was dispersed by evaporation and flows down tidal channels through the marsh to Nueces Bay. Lower marsh inundation (Figure 2) occurred daily during most of April and May when tides were at their peak.

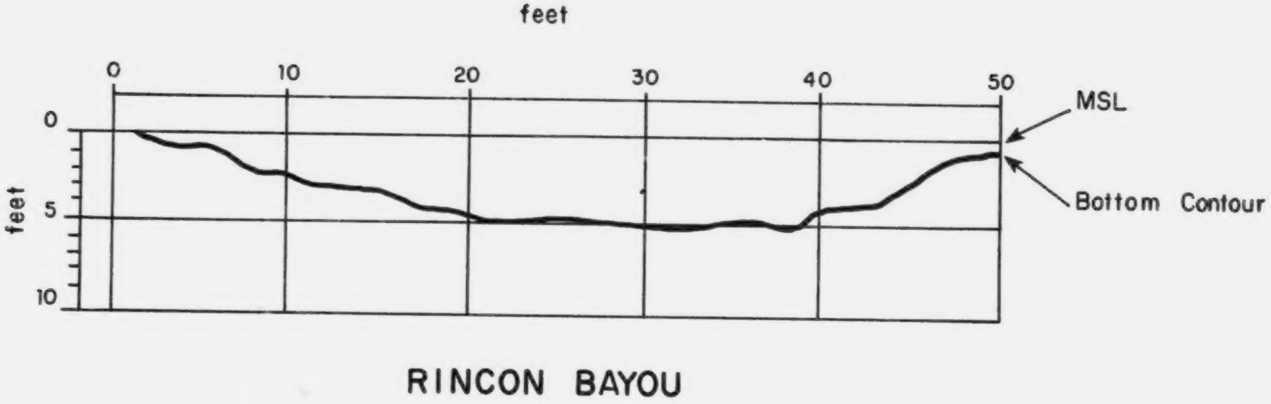

Figure 3. Cross sectional area map of the Rincon Bayou at its mouth as developed for flow volume determinations.

Water depth on the marsh flood during these peak-tide events varied according to land elevation and time of day but usually averaged between 6 and 10.5 cm.

The obvious results of this study were (1) that nutrient concentrations present in flood and ebb tides were similar (Table 1) and followed one another very closely on a temporal basis (Figure 4 and 5) and (2) that based on the eight-month study period there was a net import of nutrients into the Nueces deltaic marsh (Table 2). Although a net import of C, N, and P was documented, periods where nutrients (C, N, and P) were exported from the system were also observed.

Total organic carbon (TOC) and particulate organic carbon (POC) concentrations reflected the low marsh flooding event that occurred during May (Table 1). During this event, TOC and POC concentrations reached their maximum levels of 12.6 and 6.8 g/m^3, respectively, on the ebb tide. Flood tide values were 10.5 and 5.5 g/m^3 respectively.

Transport rates of TOC and POC were highest during April and May because it was during these months that flood and ebb tide flows were at their highest recorded levels (Table 2). During these high spring tides mean transport rates of 70 kg/hr of TOC and 32 kg/hr of POC into the marsh were observed. Net transport derived from these dates represented 43 percent and 55 percent respectively of the TOC and POC import that occurred in the eight-month study period. Most of the TOC and POC exported from the marsh occurred during February when the difference in tidal inflows and outflows were greatest. Transport rates observed during this period were 34 and 20 kg/hr for TOC and POC respectively. This amounted to 53 percent and 31 percent respectively of the net TOC and POC export. Transport of POC, whether during export or import, was generally 40 to 50 percent of the TOC transport.

Inorganic carbon concentration tended to vary between tides and months during the study period (Table 1). Transport rates varied as a function of tidal flows with 40 percent of the transport occurring in April. During this month, a mean of 435 kg/hr of IC was being imported to the marsh. The period of largest export was during February when an average of 136 kg/hr was transported to the bay representing 51 percent of the export of IC.

Like carbon, total and orthophosphorus were imported into the marsh during the course of the study. It is interesting to note that both forms were imported in similar amounts. Net transport rates of 11.97 and 9.43 kg/hr for total and ortho-phosphorus respectively were observed. Examination of the data also revealed that most of the transport occurred during mid and late spring when tides (flood and ebb) were at their maximum.

Throughout the study period ammonia and organic nitrogen were the most actively transported nitrogen forms. Organic nitrogen and ammonia were imported into the marsh at rates of 19.7 and 1.5 kg/hr respectively (Table 2). Although ammonia and organic nitrogen were exported during most of the fall and winter months, this export only represented 26 percent and 21 percent respectively of the net flux for these two parameters. In comparison, export rates of nitrate and nitrite nitrogen, during the same period, represented

Table 1. Nutrient concentrations in the Nueces marsh (Rincon Bayou) during flood and ebb tides for the period October 1978 - June 1979.

		CONCENTRATION (grams/m^3)								
MONTH	TIDE STAGE	NITRATE NITROGEN	NITRITE NITROGEN	AMMONIA NITROGEN	ORGANIC NITROGEN	TOTAL PHOSPHORUS	ORTHO-PHOSPHORUS	TOTAL ORGANIC CARBON	PARTICULATE ORGANIC CARBON	INORGANIC CARBON
October	Flood	.04	< .02	.08	1.3	.19	.13	6.0	3.4	39
	Ebb	.05	< .02	.12	1.2	.21	.12	6.3	3.6	35
November	Flood	< .02	< .02	.09	1.4	.29	.13	5.7	4.9	34
	Ebb	< .02	< .02	.06	1.5	.27	.14	5.4	4.3	30
December	Flood	.05	< .02	.05	.50	.12	.04	2.9	1.4	34
	Ebb	.04	< .02	.04	.50	.08	.01	4.9	2.9	33
February	Flood	.07	< .02	.2	1.0	.11	.04	4.1	2.8	31
	Ebb	.14	< .02	.2	.9	.18	.06	5.7	3.1	28
March	Flood	.02	< .02	.10	.86	.24	.13	7.2	3.5	35
	Ebb	.02	< .02	.14	.95	.18	.13	5.3	1.5	37
April	Flood	.05	< .02	.13	.88	.45	.36	5.5	1.0	36
	Ebb	.07	< .02	.06	.80	.24	.21	5.5	.5	38
May	Flood	.06	< .02	.03	.81	.26	.21	10.5	5.5	33
	Ebb	.02	< .02	.06	.70	.24	.20	12.6	6.8	32
June	Flood	.07	< .02	.14	1.1	.33	.18	3.2	1.6	24
	Ebb	.09	.02	.18	1.0	.34	.21	3.4	.14	28

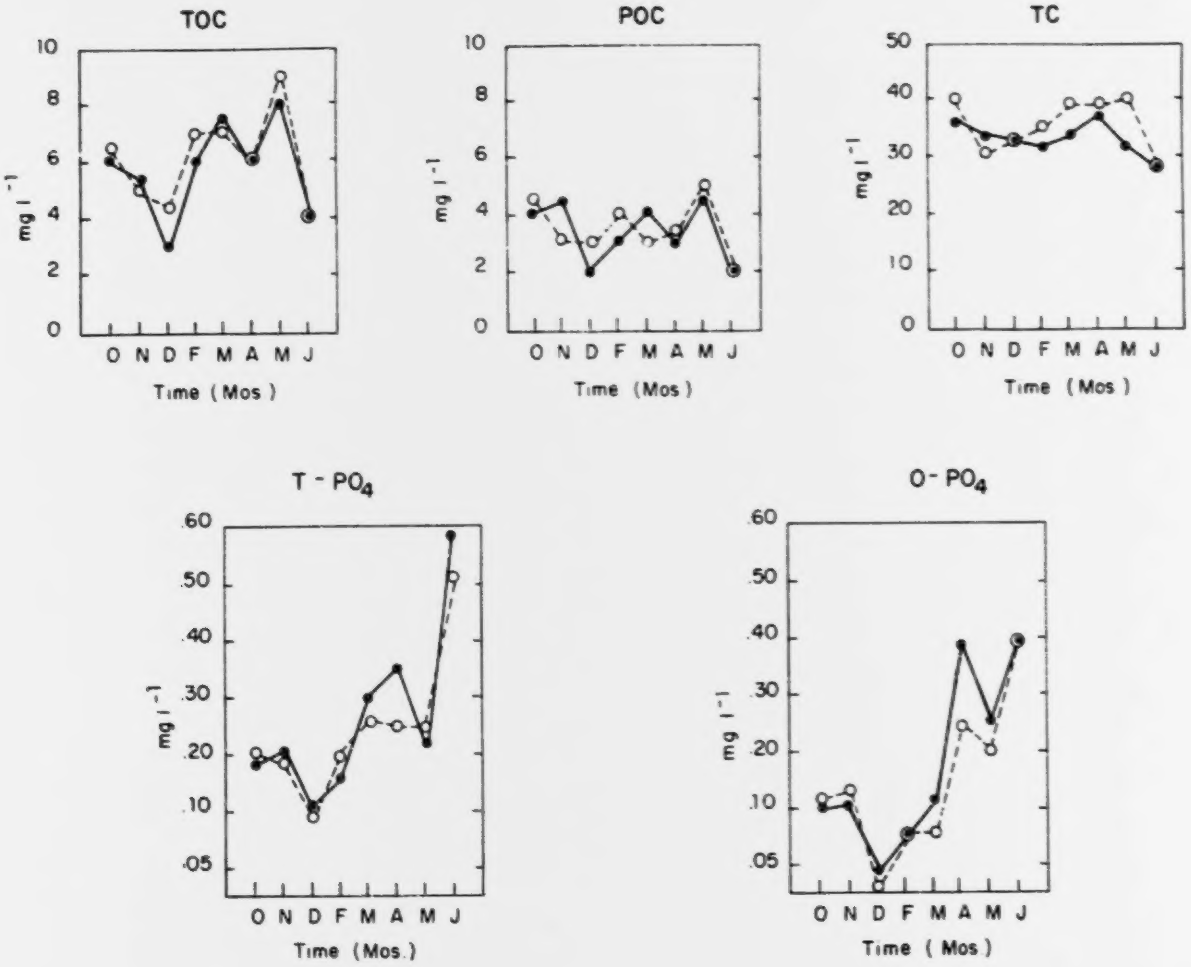

Figure 4. Temporal trends in carbon (TOC, POC, and IC) and phosphorus (T-PO$_4$ and O-PO$_4$) concentrations in the Rincon Bayou waters during the study period (October 1978 - June 1979). High tide concentrations (●—●) and low tide concentrations (O---O) were determined by averaging slack and mean tide values, and are significantly different at the 95% confidence level.

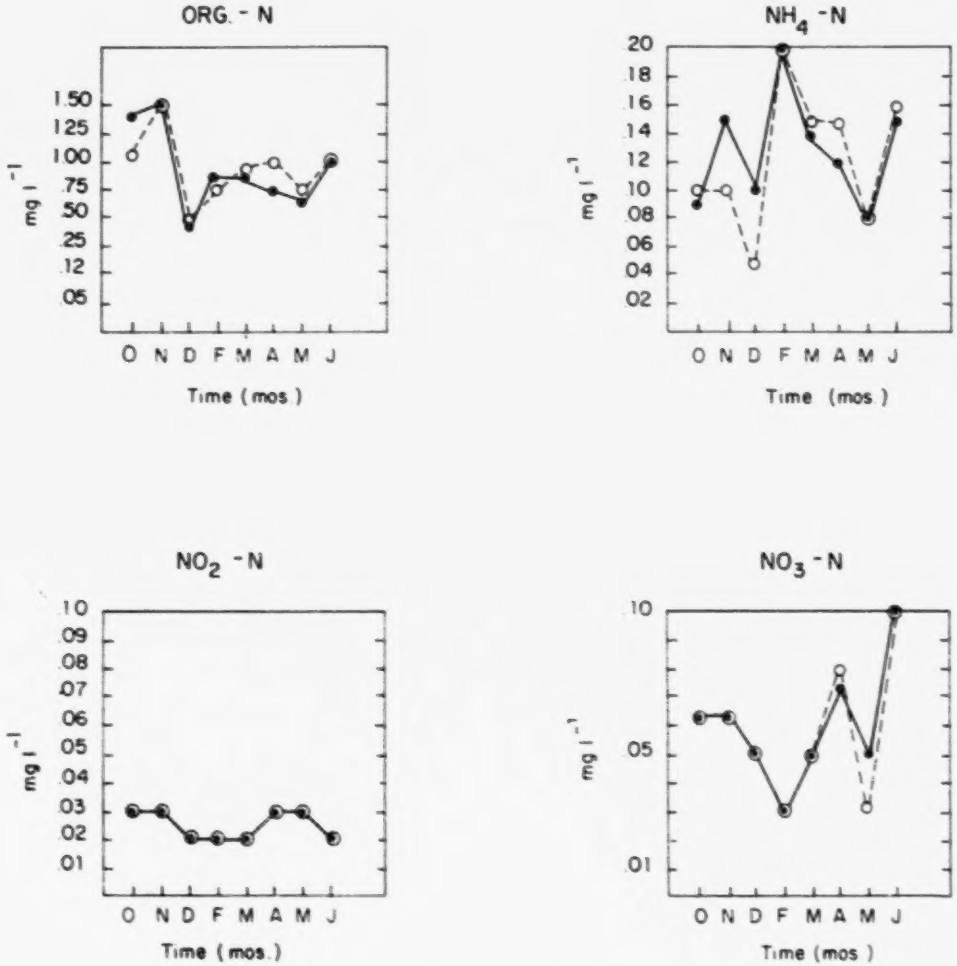

Figure 5. Temporal trends in nitrogen forms (Org-N, NH$_4$-N, NO$_2$-N, and NO$_3$-N) in the Rincon Bayou waters during the study period (October 1978 - June 1979). High tide concentrations (●—●) and low tide concentrations (0---0) were determined by averaging slack and mean tide values and are significantly different at the 95% confidence level.

Table 2. Nutrient transport rate and flow rate data generated during flood and ebb tides at the mouth of the Rincon Bayou for the period October 1978 - June 1979. Transport rates and flow rates are expressed in kg/hr and m^3/sec, respectively.

MONTH	TIDE STAGE	MEAN TIDE FLOW (m^3/sec)	NUTRIENT TRANSPORT RATES (kg/hr)								
			NITRATE NITROGEN	NITRITE NITROGEN	AMMONIA NITROGEN	ORGANIC NITROGEN	TOTAL PHOSPHORUS	ORTHO-PHOSPHORUS	TOTAL ORGANIC CARBON	PARTICULATE ORGANIC CARBON	INORGANIC CARBON
October	Flood	2.67	.38	.20	.76	12.5	1.8	.96	57.7	33.6	374.9
1978	Ebb	2.80	.5	.20	1.2	12.1	2.0	1.2	63.5	36.3	352.8
Difference			-.28	0	-.44	+ .4	-.2	-.24	-5.8	-2.7	+22.1
November*	Flood	.59	.04	.04	.19	3.3	.62	.25	12.1	10.4	72.2
1978	Ebb	1.32	.09	.09	.29	7.1	1.28	.64	25.7	20.4	142.0
Difference			-.05	-.05	-.10	-3.8	-.66	-.39	-13.6	-10.0	-69.8
December*	Flood	3.56	.58	.26	.64	6.41	1.79	.51	37.2	17.9	423.0
1978	Ebb	3.43	.43	.25	.49	6.17	.98	.12	60.6	35.8	401.3
Difference			+.15	+.01	+.15	+.24	+.81	+.39	-23.3	-17.9	+21.7
February	Flood	.86	.22	.06	.62	3.09	.31	.12	12.7	8.7	95.9
1979	Ebb	2.30	1.16	.16	1.60	7.45	1.49	.49	47.2	25.7	231.8
Difference			-.94	-.10	-.98	-4.36	-1.18	-.37	-34.5	-17.0	-135.9

Table 2. Nutrient transport rate and flow rate data (cont'd.)

			NUTRIENT TRANSPORT RATES (kg/hr)								
MONTH	TIDE STAGE	MEAN TIDE FLOW (m^3/sec)	NITRATE NITROGEN	NITRITE NITROGEN	AMMONIA NITROGEN	ORGANIC NITROGEN	TOTAL PHOSPHORUS	ORTHO-PHOSPHORUS	TOTAL ORGANIC CARBON	PARTICULATE ORGANIC CARBON	INORGANIC CARBON
March	Flood	2.35	.17	.17	.85	7.3	2.3	1.1	60.9	29.6	296.1
1979	Ebb	1.07	.07	.07	.53	3.5	.70	.50	20.4	5.8	142.5
Difference			+.10	+.10	+.32	+3.8	+1.6	+.60	+40.5	+23.8	+153.6
April	Flood	8.61	1.54	.62	4.02	27.3	13.9	11.60	170.5	40.0	1116.0
1979	Ebb	4.98	1.25	.36	1.07	14.3	4.8	3.76	98.6	8.9	681.3
Difference			+.29	+.26	+2.95	+13.0	+9.1	+7.84	+71.9	+31.1	+434.7
May	Flood	5.59	1.20	.40	.60	16.3	5.2	4.2	211.3	110.7	664.0
1979	Ebb	3.19	.23	.23	.69	8.1	2.7	2.2	144.7	78.1	367.5
Difference			+.97	+.17	-.09	+8.2	+2.5	+2.0	+66.6	+32.6	+296.5
June	Flood	4.76	1.50	.34	2.70	18.8	5.65	3.1	53.6	27.4	475.5
1979	Ebb	4.62	1.50	.34	3.00	16.6	5.65	3.5	56.5	2.32	465.7
Difference			0	0	-.30	+2.2	0	-.4	-2.9	+25.1	+9.6
NET FLUX			+.24	+.39	+1.5	+19.7	+11.97	+9.43	+98.9	+65.0	+618.7

*The mean flow rates shown for these months were determined by regression analysis using rainfall and tide flow data generated by the U.S.G.S. in Corpus Christi.

45 percent and 20 percent respectively of their net flux. It is apparent then that, (1) the winter export of all nitrogen parameters is overshadowed by the larger imports observed during the spring, and (2) nitrate and nitrite nitrogen are exported in nearly the same percentages as ammonia and organic nitrogen. As was the case with carbon and phosphorus transport rates, fluxes were greatest during the periods of high flood and ebb tides (i.e., during April and May).

DISCUSSION

Our data indicate that the Nueces Deltaic marsh served as a nutrient sink during our eight-month study period. The fact that we found the Nueces marsh serving as a nutrient sink agrees with a seasonal study performed by Espey, Huston, and Associates (1977). Other investigators (Ho et al. 1970; Pomeroy et al. 1972; and Valiela et al. 1973) have also suggested that tidal marshes may act as nutrient sinks. However, most investigations have determined that brackish marshes tend to export C, N, and P on an almost continuous basis (Armstrong and Gordon 1977; Dawson and Armstrong 1975; Armstrong and Hinson 1977; and Heinle and Flemer 1976). Thus, the Nueces marsh offers an interesting contrast to the normally encountered brackish marsh system, at least with respect to nutrient transport.

The Nueces marsh is unlike most river-impacted tidal and brackish marshes in that it is totally inundated only on rare occasions. Historical data compiled by the Texas Water Development Board (1958-1979) indicate that Nueces River spills occur on an average of only 22 days a year. The reason for this is that the Nueces River must reach a flow rate in excess of 3000 cfs in order to top its bank and flood the marsh. Apparently with such infrequent flooding, it would then appear that most of the annual nutrient transport occurring in the marsh system would depend mostly on tidal inundation. Obviously, during wet years when flooding occurs more frequently and is of longer duration, the importance of nutrient flux on tidal flows will tend to be lower relative to total nutrient flux.

From the data in Table 1, quantified nutrient flux in the Nueces marsh appears slight relative to other studies (de la Cruz 1965, Teal 1962), even though there is a definite import phenomenon occurring. Carbon transport data in our study is positive--that is, we found carbon to be imported. Teal (1962), on the other hand, suggest that as much as 45 percent of the net production of a Spartina sp. marsh is available for export (as detritus). De la Cruz (1965) described similar occurrences when he measured suspended and floating particulate organic matter in a Georgia marsh and found that 19 to 29 percent of the annual net production may be exported to the estuary.

The fact that the importation of particulate organic carbon (which amounted to 66 percent of the TOC) was so high, is not so unusual because most of the import occurred during the spring when low detrital production and increasing planktonic populations are observed. Thus, the higher TOC and POC concentration on flood tides would be expected. Chanley (1957) has also suggested that low export of TOC and POC, especially in the higher elevation marshes, could possibly be due to the utilization of detritus in the production of peat or peat-related material.

Phosphorus concentrations that we observed are similar to those encountered by Heinle and Flemer (1976) in the Patuxent Estuary, but were somewhat higher than those measured by Pomeroy et al. (1962) in Doboy Sound, Georgia. The overall importation of phosphorus into the Nueces marsh leads us to suspect that perhaps the marsh is somewhat phosphorus limited. This appears to contradict the findings of Armstrong and Gordon (1977) who found phosphorus to be passively exported by flood and tidal waters in a similar marsh environment. They concluded that net exportation of phosphorus indicated that an excess of this nutrient was present and therefore was not a limiting factor to plant production. Our data suggest that had we monitored the transport of phosphorus in July, August, and September of 1979, we may have indeed seen a net export of phosphorus since the June concentration showed a net flux of 0 and 0.4 kg/hr of total and ortho-phosphorus, respectively, out of the marsh. However, the definite importation of both total and ortho-phosphorus during the spring months and the fact that ortho-phosphorus constituted 80 percent of the net phosphorus flux, indicates that phosphorus is not in excess in this system. Similar findings that support this hypothesis were reported by Espey, Huston, and Associates (1977).

Several investigators (Valiela et al. 1973, Van Raalte et al. 1974, and Valiela and Teal 1974) have suggested that free nitrogenous nutrients are readily utilized in marsh ecosystems. Valiela and Teal (1974) observed increases in the standing crop of Spartina sp. following the application of a high nitrogen fertilizer (without phosphorus), thus suggesting that higher salinity marshes are nitrogen limited. Our data tend to agree with these studies, because we observed that there was a net flux into the marsh of both organic and inorganic nitrogen. The fact that most of this importation occurred during the spring growing season reinforces the nutrient-limiting concept.

The higher organic nitrogen values (0.5 to 1.5 g/m^3 observed on flood and ebb tides during the fall and winter coincide with the vegetational dieback and decomposition occurring at this time. Inorganic nitrogen (NO$_3$ and NO$_2$) concentrations were low (0.07 g/m^3) throughout the study period. In fact, the net flux for each form was close to zero suggesting that perhaps inorganic nitrogen demands within the marsh are just barely being met by allocthonous inputs of inorganic nitrogen. This supposition would seem logical if the system was not impacted by other sources of nitrogen, such as river spills, agricultural runoff, and sewage contamination. Since the reported concentrations of inorganic nitrogen are at or near their detectability limits and no other sources of nitrogen were considered in the estimation of inorganic nitrogen transport, little credence can be given to our estimates of direction and magnitude of net fluxes of inorganic nitrogen.

CONCLUSION

Nutrient transport in the Nueces marsh appears to be rather atypical when compared to other high salinity riverine marsh systems. It is characterized by infrequent and incomplete inundation by both flood and tidal waters and tends to serve as a nutrient sink. It appears to be a system where tidal flow contributes significantly to the transport of nutrients. Nutrient concentrations within a tide are not as critical to the determination of net flux as is the flow rate between flood and ebb tides. The fact that similar amounts of nitrogen and phosphorus were imported into the Nueces marsh suggests that both of these forms could be limiting nutrients for this system.

The transport data generated in this study are meaningful in that they begin to describe the nutrient flux of a rather unique estuary. However, in order to fully describe nutrient transport in the Nueces marsh, a study period of 12 to 24 months should be employed. In addition, as many of the point and nonpoint sources of nutrients as possible (such as agricultural runoff, rainfall, sewage contamination, river spills, etc.) should be considered in the experimental design of the study. Vegetational and sediment exchange rates would also be very helpful in the determination of nutrient flux within as well as between the marsh and the estuary. Only in this way can nutrient transport between the Nueces marsh and Nueces estuary be accurately assessed.

ACKNOWLEDGEMENTS

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LITERATURE CITED

American Public Health Association. Standard methods for the examination of water and wastewater. 14th ed. Washington, D.C: APHA; 1975; 874p.

Armstrong, N.E.; Gordon, V.N. Exchange rates for carbon, nitrogen, and phosphorus in Nueces and San Antonio Bay marshes. Report to the Texas Water Development Board for IAC (76-77)-0610 by the Center for Research in Water Resources. Austin, TX: The University of Texas at Austin. CRWR-152, EHE 77-05. 1977.

Armstrong, N.E.; Hinson, M.O. Jr. Influence of flooding and tides on nutrient exchange from a Texas marsh. Proceedings of the Forth Biennial International Estuarine Research Conference. 1977, October 2-5. Estuarine Research Federation, Mt. Pocono, PA., (in press).

Benton, A.R., Jr.; Hatch, S.L.; Kirk, W.L.; Newman, R.M.; Shell, W.W.; Williams, J.G. Monitoring of Texas coastal wetlands. College, Station, Texas A&M Remote Sensing Center, Texas A&M University, TX; 1977.

Chanley, P.E. Survival of some juvenile bivalves in water of low salinity. Proc. Natl. Shellfish Association. 48:52-56, 1957.

Cruz, de la, A. Study of particulate organic detritus in a Georgia salt marsh estuarine ecosystem. Athens, GA: University of Georgia. 1965:141p. Dissertation.

Dawson, A.J.; Armstrong, N.E. Exchange of carbon nitrogen, and phosphorus in Lavaca Bay, Texas Marshes. Volume II, The role of plants in nutrient exchange in the Lavaca Bay brackish marsh system. Report to the Texas Water Development Board by the Center for Research in Water Resources. Austin, TX: The University of Texas CRWR 129, EHE-75-06. 1975.

Espey, Huston, and Associates. Marsh biology and nutrient exchange studies of three Texas estuaries. Report to Texas Department of Water Resources, Austin, Texas. 1977; 450p.

Heinle, D.R.; Flemer, D.A. Flows of materials between poorly flooded tidal marshes and an estuary. Mar. Biol. 35: 359-373; 1976.

Henley, D.E.; Rauschuber, D.G. Freshwater needs of fish and wildlife resources in the Nueces-Corpus Christi Bay area, Texas: a literature synthesis. U.S. Fish and Wildlife Service, Office of Biological Services, Washington, DC. FWS/OBS-80/10; 1981; 410p.

Ho, C.L.; Schweinsberg, E.H.; Reeves, L. Chemistry of water and sediments in Barataria Bay. Baton Rouge, LA: Louisiana State Univ. Coastal Series 5:4-56; 1970.

Menzel, D.W.; Vaccaro, R.F. The measurement of dissolved organic and particulate carbon in seawater. Limnol. Oceanogr. 9:138-142; 1964.

Pomeroy, L.R., ; Shenton, L.R.; Jones, R.D.H.; Reimold, R.J. Nutrient flux in estuaries. Spec. Symp. Am. Soc. Limnol. Oceanogr. 1: 274-291; 1972.

Strickland, J.D.H.; Parsons, T.R. A manual of seawater analysis, Bull. Fish. Res. Bd. Can. 125: 1-203; 1965.

Teal, J.M. Energy flow in a salt marsh ecosystem of Georgia. Ecology 43:614-624; 1962.

Texas Department of Water Resources. Open computer files on Texas river flow and rainfall data. 1958-1979.

Valiela, I.; Teal, J.M. Nutrient limitations in salt marsh vegetation. Reimold, R.J. Queen, W.H. eds Ecology of halophytes. New York: Academic Press; 1974:547-563.

Valiela, I.; Teal, J.M.; Sass, W. Nutrient retention in salt marsh plots experimentally fertilized with sewage sludge. Estuarine Coastal Mar. Sci. 1:261-269; 1973.

Van Raalte, C.D., Valiela, I.; Carpenter, E.J.; Teal, J.M. Inhibition of nitrogen fixation in salt marshes measured by acetylene reduction. Estuarine Coastal. Mar. Sci. 2:301-305; 1974.

DISCUSSION

Question: Scott Nixon, University of Rhode Island. One thing before we start speculating on the marsh being a source or a sink or comparing the different systems is the problem of making the paths there. You have made the point that the concentration difference between the flood and ebb tides is very small. The net flux you have come up with is essentially a result of water balance; therefore, we have to account for the water budget. This marsh is consuming water over the year, so we have to reconcile the fate of the stored water. I'm wondering, in light of the work done at South Carolina and Virginia in trying to address the problem, how hard it is to get a good mass balance through the bridgeway with the current meter measurements or area height models? How good do you think your measurements really are when it comes to coming up with an average concentration and a one spot velocity measurement in the pass?

Answer: We noticed that the tidal amptitude is very low in this area, that the current speeds were very slow by measuring the current with a weighted float technique. This may not be state-of-the-art, but it proved to replicate itself very well during each measurement. Since the nutrient portion of this study was a small part of the overall study, I felt that at the time it was the best that we could do. I hope that answers your question.

Question: Brian Fry, Port Aransas Marine Lab. I was wondering, is it possible that the water measured on the flood tide actually comes back on the ebb tide; that actually this marsh is not very well flushed but the water just goes say a hundred meters downstream and then comes right back?

Answer: Well, our measurements were taken at two locales (1) where the Rincon Bayou intercepts the Nueces Bay and (2) approximately two miles up the bayou in the marsh. We noticed, via staff gauges, significant changes in tidal amplitude at both measurement stations indicating substantial water movement. However, since the marsh is in a low tidal amplitude area, most tidal pools and tidal channels are not completely drained during a complete tidal cycle. Thus, in answer to your question it is possible that flood and ebb tide waters are one and the same with respect to nutrient and particulate content and that the marsh is not very well flushed. It is, however, difficult to imagine that this phenomenon is more the rule than not and that very little bay water is actually transported in and out of the marsh system.

ESTUARINE BENTHIC COMMUNITY DYNAMICS RELATED TO FRESHWATER INFLOW TO THE CORPUS CHRISTI BAY ESTUARY

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ABSTRACT

In September 1979 Corpus Christi Bay was impacted by tropical storm-intensity rains that resulted in an intensive period of freshwater inflow to the bay, dramatically decreasing salinity below normal levels for more than a month. The existence of an historical data base on benthic infauna for this estuary allowed an investigation to be conducted concerning effects of this intensive freshwater inflow on the estuarine benthos. Several months after the inflow event, densities of dominant infaunal populations increased to levels never observed and productivity of the benthos, as represented by biomass changes, increased substantially over previous years. We speculated that the nutrients associated with the intensive freshwater inflow increased the primary productivity of the estuarine ecosystem. This increased productivity was, in turn, eventually reflected by the benthos. These data may provide a missing link in the correlations between freshwater inflow events in south Texas estuaries and yields of some of the important fisheries such as shrimp.

INTRODUCTION

Bays and estuaries along the coastline of the northwestern Gulf of Mexico are strongly influenced by freshwater inflow and its associated nutrients. This is true primarily because these bays and estuaries are located in a semi-arid climate receiving usually less than 70 cm of rainfall per year (Flint and Rabalais 1981). It is thought that in these hypersaline systems, freshwater inflow, which is very unpredictable in nature, affects estuarine community species composition, the vitality and productivity of estuarine food chains, and the harvests of many fisheries related to the estuarine ecosystem, such as shrimp. The links between the inflow of fresh water and the resulting effects as reflected by the changes in fishery harvest, however, are presently not well understood.

During the 24-hour period beginning with the evening of 18 September 1979, an extensive low pressure system engulfed the south Texas coast and heavily impacted the Corpus

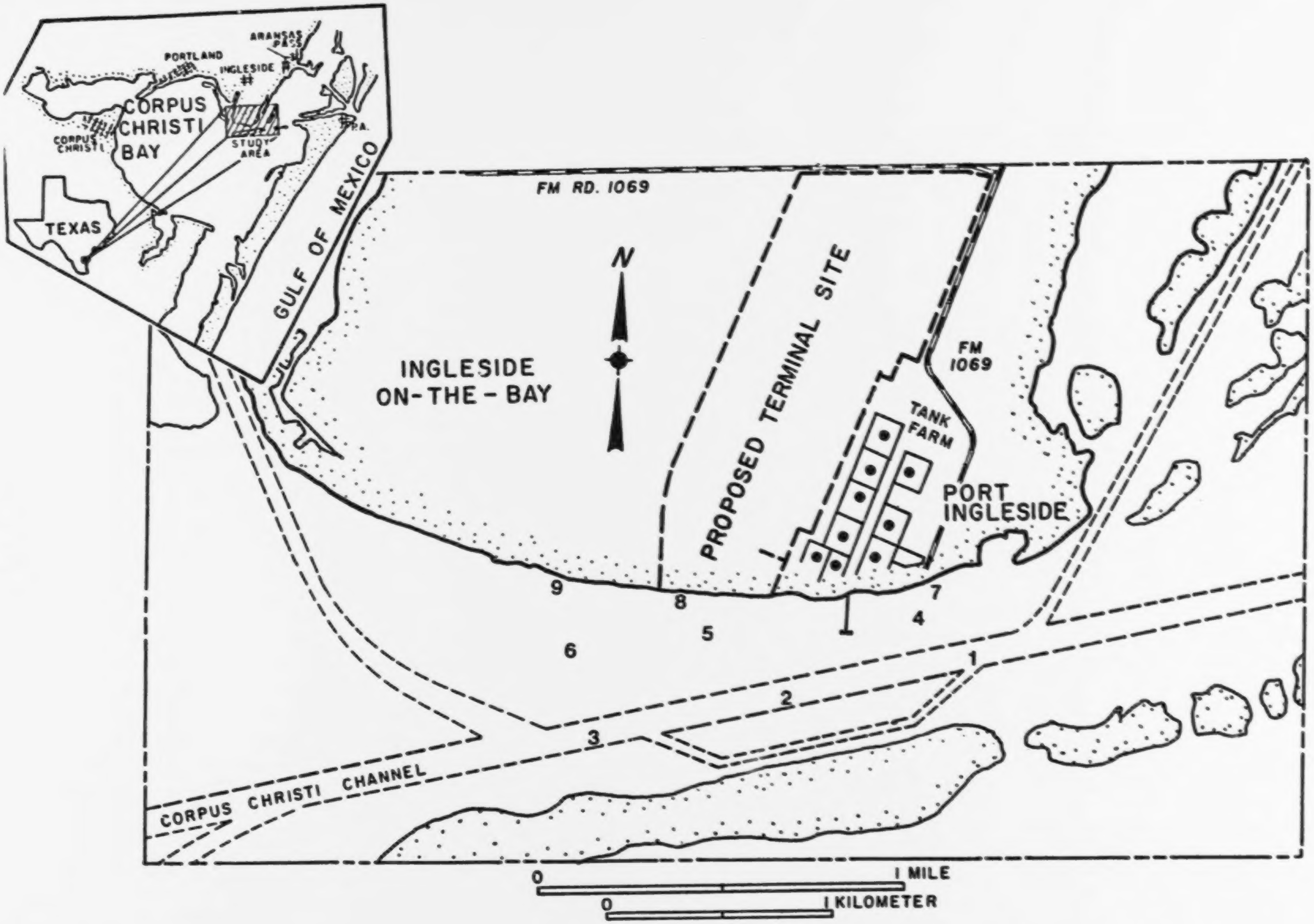
ARANSAS PASS
PORTLAND
INGLESIDE
CORPUS CHRISTI BAY
CORPUS CHRISTI
STUDY AREA
P.A.
TEXAS
GULF OF MEXICO
FM RD. 1069
N
INGLESIDE ON-THE-BAY
PROPOSED TERMINAL SITE
FM 1069
TANK FARM
PORT INGLESIDE
9
8
7
6
5
4
1
2
3
CORPUS CHRISTI CHANNEL
0
1 MILE
0
1 KILOMETER

Figure 1. Map of the Corpus Christi ship channel area near Ingleside, Texas showing sampling locations, Stations 1-6.

Christi area with tropical storm-intensity rains that reached as much as a 33 cm accumulation in 24 hours. The results of this intensive storm produced a large amount of riverine input and land runoff to the estuarine system associated with the Aransas Pass Inlet and Corpus Christi Ship Channel (Figure 1). The impact of this massive freshwater inflow event to the system was reflected by an extensive period of continual low salinities measured in the Corpus Christi Bay estuarine system. This prolonged period of lowered salinity measurements ranging around 18 parts per thousand occurred from approximately 20 September to 27 September 1979. Salinities remained well below expected seasonal levels through the middle of October 1979. This storm event, with its associated high freshwater inflow to the estuaries, proved to be relatively unique to the area with freshwater inputs having not occurred with such intensity since Hurricane Beulah in 1967.

At the time of this event, we had recently completed a five-year survey (1974 to 1979) based upon monthly sampling to investigate the community structure and dynamics of the estuarine benthos in the area of Corpus Christi Bay as illustrated in Figure 1. This provided us with an extensive baseline of data on benthic macrofauna ecology preceding the climatic events described above. By continuing the basic sampling design in this area after September 1979, we were able to compare the events in the benthos that occurred after the storm with the historical data base and to infer the effects of freshwater inflow on the fisheries of the area. Specifically, we resampled two stations (1 and 4) from the original sampling design; Stations 1 and 4 represented two different habitats as evidenced by our five previous years of benthic data collection.

METHODS

Monthly collections were continued at stations 1 and 4 (Figure 1) as they had been for the previous five years (Flint and Younk in press). The sampling months included October-December 1979 and January -April 1980.

Benthic samples were obtained from the stations during each month of sampling duration using a $0.09m^2$ modified Petersen grab. Triplicate samples were taken at each collection site during the study period. The contents of the grabs were washed through a 500μ mesh screen and the retained material preserved in a 10 percent formalin solution. Benthic macroinvertebrates were separated from the debris in the laboratory by examination under a stereo dissecting microscope, identified to lowest possible taxa, and counted. Wet weight biomass was measured for each total sample plus individually for the dominant taxa. A 15 percent weight correction was done to compensate for increase in weight due to preservative effects (Mills and Fournier 1979).

The measure of species diversity based upon species listed for each station during each sampling interval was calculated by the Shannon-Wiener diversity index (Pielou 1966) using log 10 and equitability (Lloyd and Ghelardi 1964). By combining a diversity index with measures of richness (numbers of species) and evenness (distribution of relative abundance of the species) a reasonable comparison between communities could be accomplished.

Species composition of individual sampling sites over time was compared, using the numerical classification technique of cluster analysis. The cluster analysis grouped together sampling periods which were similar in species composition and abundance. These analyses also identified species groups which were similar in distribution temporally.

Preliminary analysis of the benthic macroinvertebrate data indicated that several of the dominant species were relatively ubiquitous. Therefore, a classification technique which was unbiased toward species dominance and yet included both quantitative and qualitative information seemed desirable to employ. The Canberra-Metric similarity measure of Lance and Williams (1967) was employed to determine similarity between the entities of sampling period and infaunal species.

When choosing species to be included in the analysis, we arbitrarily chose those whose total abundance were greater than 30 individuals; this criterion alleviated the very infrequently taken species whose low abundances would have contributed very little to the overall analyses. This follows Day et al. (1971) who found that results of similar analyses were not reliable using only rare species and that similar results were obtained using data with and without the rare species. Data standardization needs were considered by checking the normality of density distributions for a number of the dominant species. The skewness and kurtosis were found to be relatively constant among samples for these species, thus allowing for the use of raw data scores in the cluster analyses (Scheefe 1959; Downing 1979).

RESULTS

PRE-EVENT TRENDS

The most dominant recurring pattern observed during the pre-event study of benthic infauna was that there was a major difference in community structure between the channel stations, 1 to 3, and the shallow water stations, 4 to 6 (Figure 1). These differences were primarily related to variations in sediment structure plus the perturbations of periodic dredging and constant shrimping and shipping activities in the channel which were not present in the shallower waters (< 5m). Therefore, for our continued observations of the benthos following the freshwater inflow event of September 1979, we chose to sample both a channel and shallow water station (1 and 4 respectively) to adequately document any changes in benthic infauna related to the event.

There were several trends in the historical benthic data that suggested we might expect changes to occur in the ecosystem as a result of a period of intensive freshwater inflow. Several significant correlations existed between both general community variables as well as individual species densities and the environmental variable of salinity. For example, total infaunal density for the historical data base was negatively correlated with salinity ($r = -0.34$, $p < 0.001$, $n = 159$), suggesting that community densities increased when salinity decreased. A polychaete population, Mediomastus californiensis, displayed a negative correlation ($r = -0.25$, $p < 0.002$, $n = 159$) with salinity. In addition, three bivalves, Mysella planulata, Mulinia lateralis, and Abra aequalis, all showed significant negative correlations of -0.43, -0.28, -0.32, respectively, with salinity ($p < 0.001$, $n = 159$).

Besides the significant correlations with salinity cited above the benthic community variables of infaunal species number and total density showed some interesting trends in relation to salinity changes between 1974 and 1979 as illustrated in Figure 2. Salinity exhibited a great deal of variation over the study period, which is typical for an estuarine habitat. There was a dramatic decrease in salinity, however, in November and December of 1976 (Figure 2). This particular decrease in salinity was followed by a jump in the number of infaunal species for all the shallow stations, representing the highest number observed during the entire study period. The most dramatic change, however, was the tremendous increase in infaunal density for the shallow stations (Transect 2) following the drop in salinity of 1976 (Figure 2). In addition to this obvious trend, there was another period of low salinity observations during the initial stages of the study, November-December 1974 (Figure 2). The number of infaunal species did not peak as in 1976 but the infaunal total densities again exhibited a large increase.

These historical patterns suggested to us that the intense rainfall that occurred in September 1979 with the resulting dramatic decreases in salinities in Corpus Christi Bay had a significant effect on the ecosystem, which was reflected by changes in benthic infaunal patterns. Therefore, we continued our study on the premise that any changes observed would provide valuable information concerning the overall functioning of this ecosystem, including effects on the important fisheries it contained.

POST-EVENT TRENDS

The actual change in salinity following the intensive rainfall of September 1979 for Corpus Christi Bay is illustrated in the 1979 (third) salinity plot of Figure 3. The salinity changes are in direct contrast to salinity records for the same seasonal period of 1977 and 1978. As mentioned earlier, estuarine salinities remained low for more than a month in the fall of 1979.

Also illustrated in Figure 3 are some of the more immediate responses in benthic infaunal populations that were observed after the inflow event. Three polychaetes (*Tharyx setigera*, and *Streblospio benedicti*) and one bivalve (*Lucina multilineata*) showed density increases that were not observed during the same time period in either 1977 or 1978 (Figure 3). In fact the densities for all species but *Mediomastus californiensis* were more than doubled in October-November 1979 as contrasted with previous years, and July-August of the same year.

Above we highlighted several instances in the historical data (pre-event) in which the number of infaunal species and total density showed significant correlations with salinity changes. As exhibited in Figure 4, however, these previous trends were small in contrast to the changes observed for these two benthic community variables after the freshwater inflow event of September 1979. Both variables reached peaks never observed before for this area of Corpus Christi Bay. It is reasonable to conclude that there was probably a cause and effect relationship between the inflow event and the increases in these two benthic infaunal variables.

Figure 5, which is a plot of equitability, the measure of evenness of the different infaunal population densities in the community,

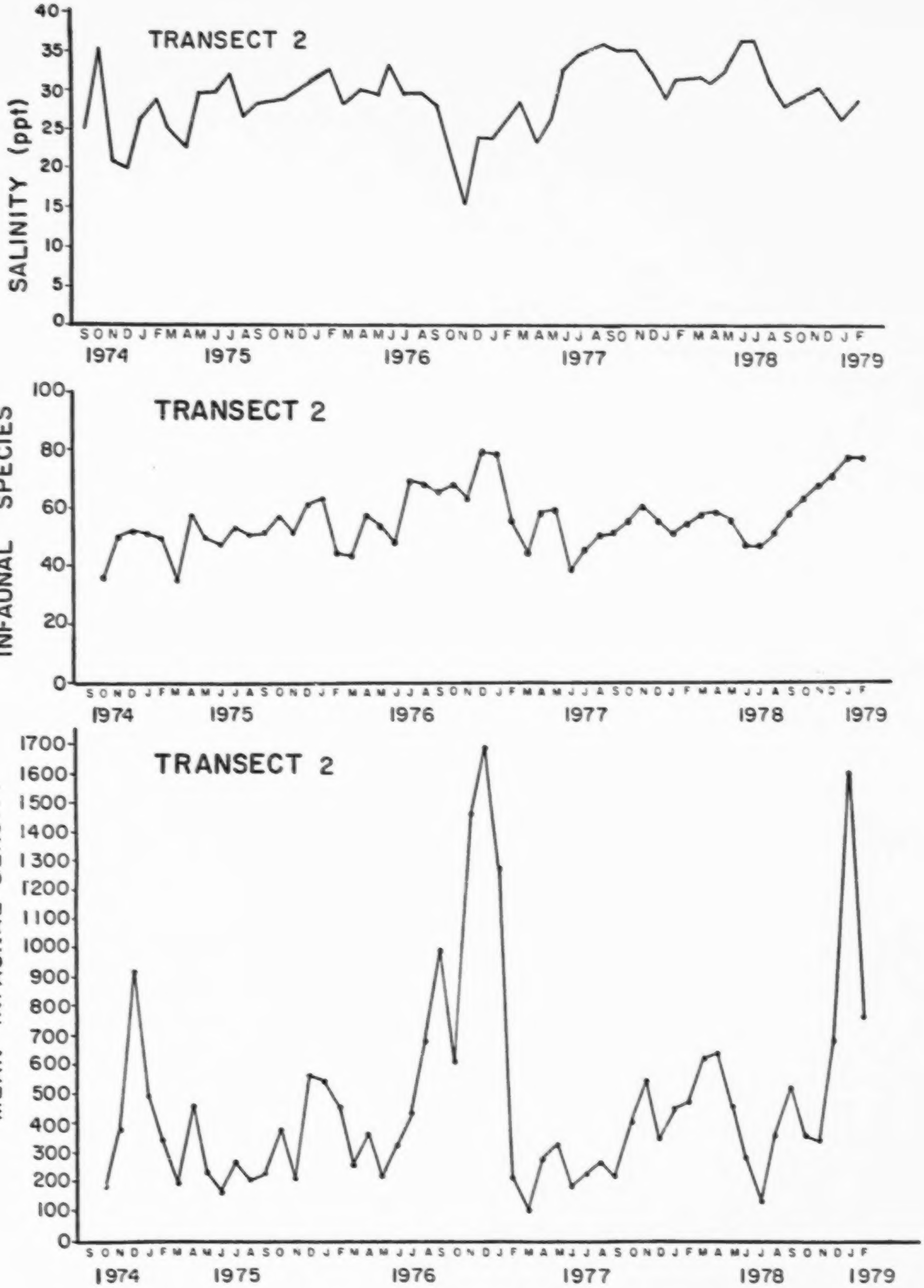

Figure 2. Plots of salinity, mean number of infaunal species and mean infaunal density (individuals/0.09m^2) between September 1974 and February 1979 for the shallow water sampling stations (transect 2, Stations 4-6).

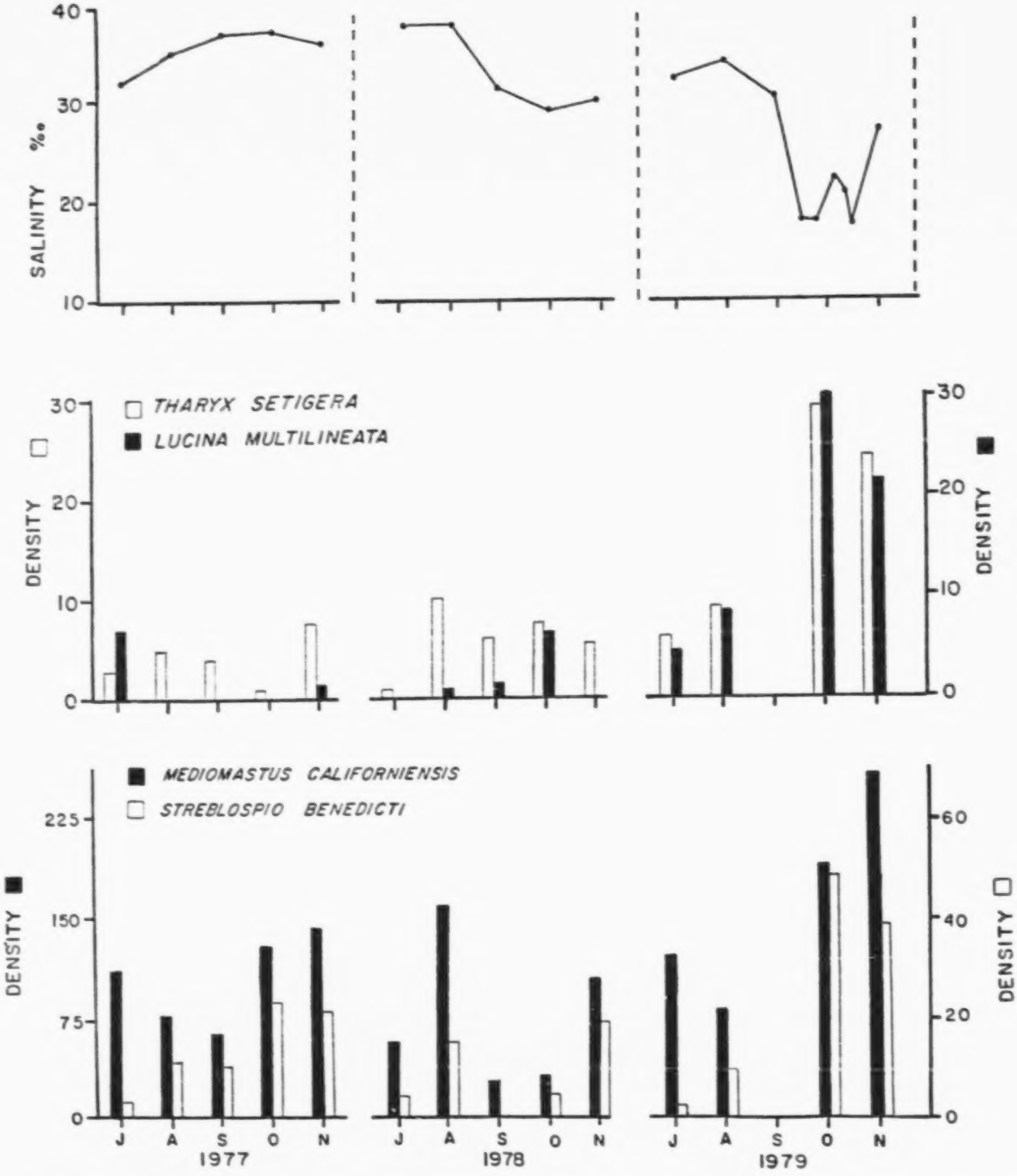

Figure 3. Comparison of late summer and early fall salinities and densities (individuals/0.09m^2) for some of the dominant infaunal species during the collection years 1977, 1978, and 1979.

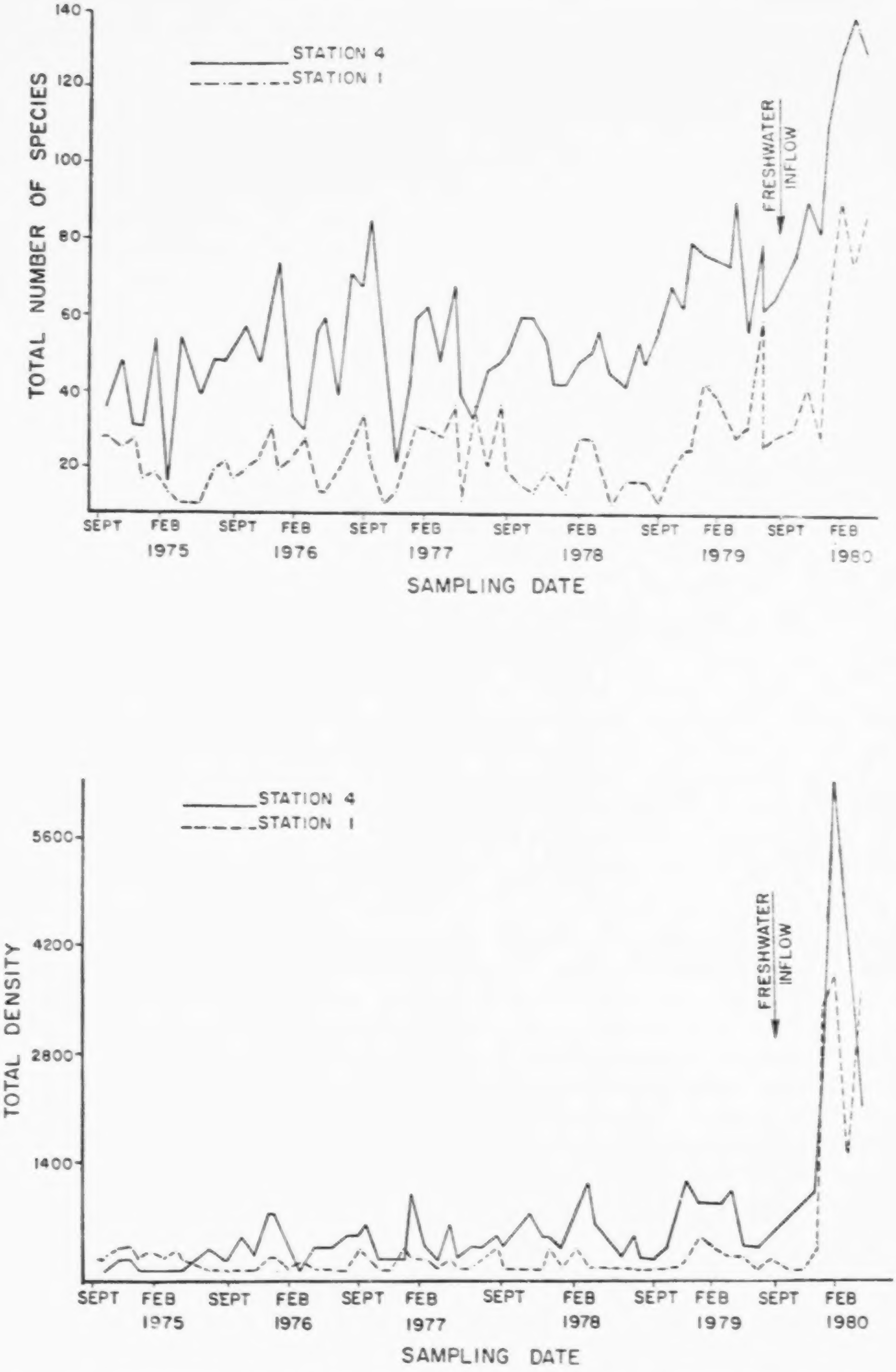

Figure 4. Comparisons of total number of infaunal species and total infaunal desities (individuals/0.09m^2) for sampling Stations 1 and 4 over the five year period prior to the freshwater inflow event of September 1979 and after this inflow period.

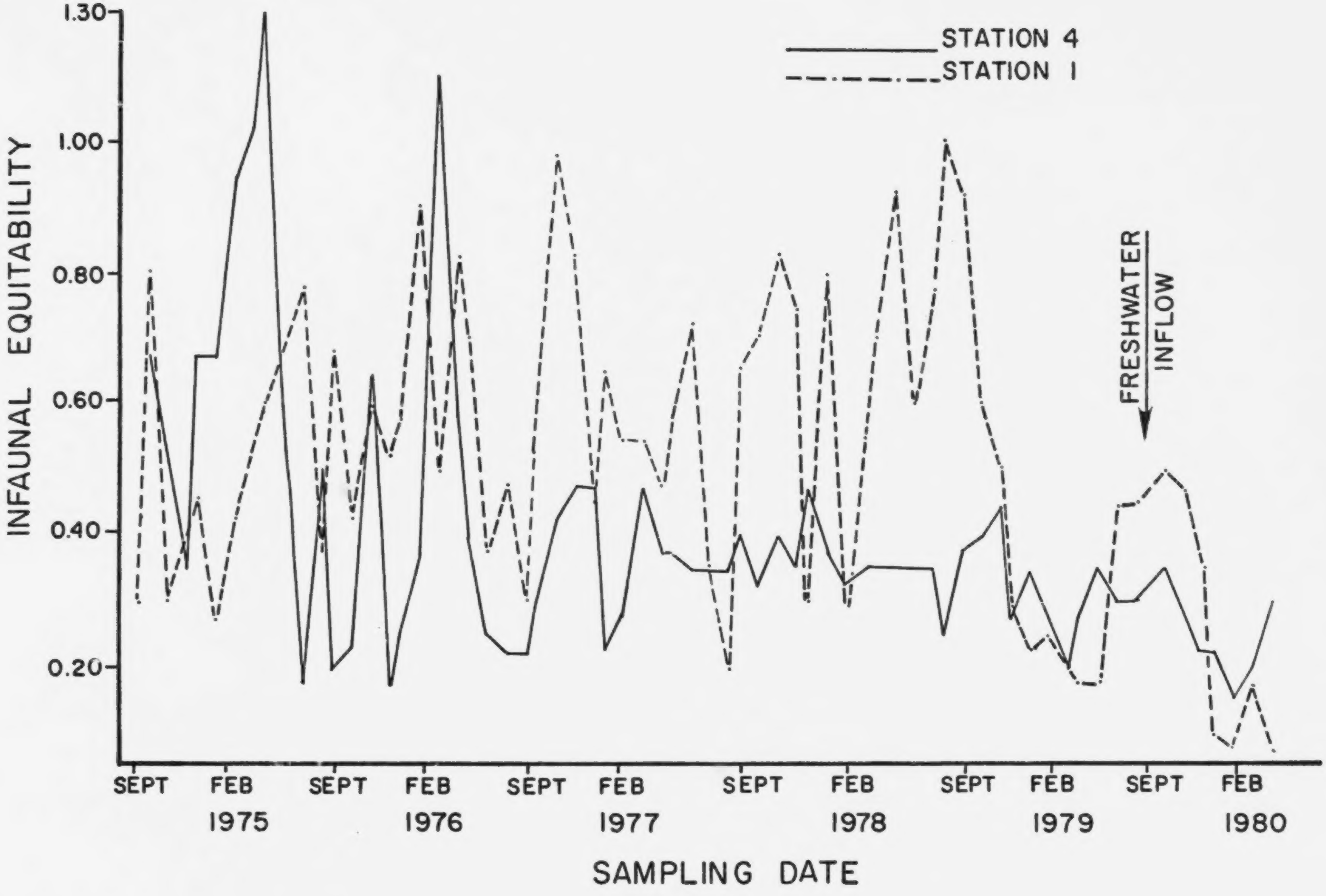

Figure 5. Comparison of infaunal equitability for sampling Stations 1 and 4 over the five-year period prior to the freshwater inflow event of September 1979 and after this inflow period.

further exhibited some of the dynamics that were occurring in the benthos after the inflow event. Equitability of the infauna varied tremendously over the entire study duration (1974 to 1979). A distinctive decrease in this community measure was observed, however, a short time after the intense freshwater inflow event, with equitabilities for the two observation stations reflecting their lowest values for the entire six years of study. This pattern suggested that although there was an increase in number of infaunal species (Figure 4) after the inflow event, the corresponding increase in total infaunal density was due to increases in a few populations which then dominated the community structure. The dominance by a few species in respect to density, caused the evenness of species distribution to drop significantly (Figure 5).

Evaluation of infaunal community structure using the numerical classification technique of cluster analysis further documented the dramatic changes that occurred in the Corpus Christi Bay benthos following the freshwater inflow event in September 1979. An examination of the similarity in community structure between all collection periods for station 1, between 1974 and 1980, with the exception of the early summer months, showed a very striking pattern (Figure 6). The period of January to April 1980 exhibited a dissimilarity with all other collection periods at a level greater than 65 percent. The dissimilarity in benthic community structure between this period and all others was strong enough to override any natural seasonal patterns that may have existed in the data. The same pattern was observed for station 4 benthic community structure.

A closer evaluation of specific time periods during the total study period served to emphasize the effect that the freshwater inflow event had on the benthos. Figure 7 compares the early fall periods (July to October) and the winter periods (December to March) for all collection years at stations 1 and 4. The highest dissimilarities observed for any collection periods for the fall were slightly over 40 percent with no significant separation for the 1979 collection periods. In contrast, the winter dendrograms exhibited highest dissimilarities around 60 percent with a distinct separation of the winter 1980 collection periods. This ability of the cluster analysis technique to separate benthic community structure characteristics of winter 1980 from all other winter periods while not being able to also separate characteristics for fall 1979 in respect to previous fall periods further indicates that the benthos was definitely changed by the freshwater inflow. Furthermore, there appeared to be a slight lag in the overall response of the benthic infauna to this natural disturbance of the estuarine ecosystem. Although the intensive inflow event occurred in September and salinities remained low well into October, the benthos did not reflect the dramtic increase discussed so far until December - January.

A very good example of these changes is derived by focusing on one of the dominant populations in the study area. Figure 8 illustrates the size class distribution for the bivalve *Abra aequalis* during February and March of 1979, prior to the inflow event and during February and March 1980, after the inflow event. Several trends are apparent.

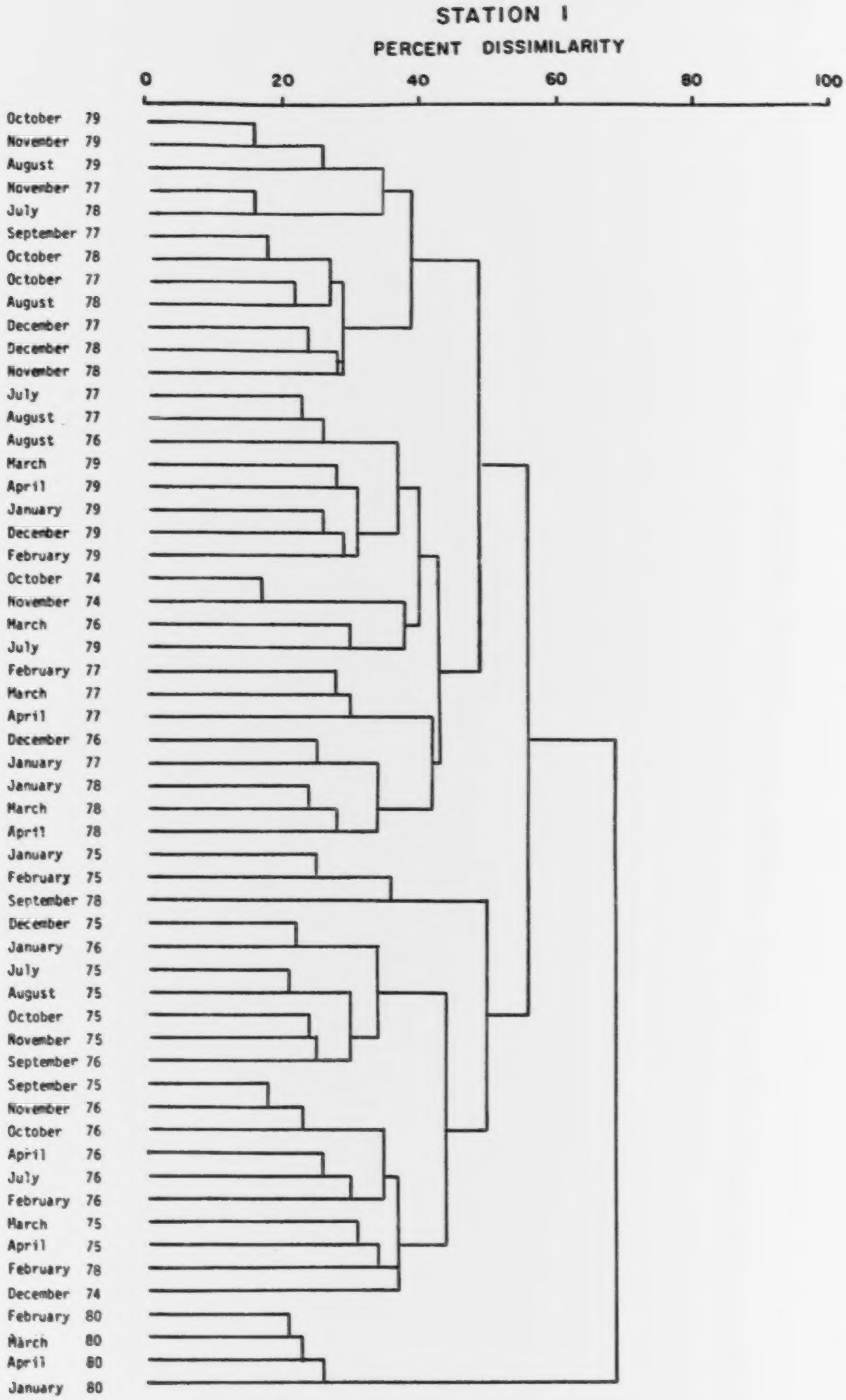

Figure 6. Dendrogram from the cluster analysis results of infaunal species composition evaluation for all collection periods at Station 1 over the study duration with the exception of the summer months, May and June.

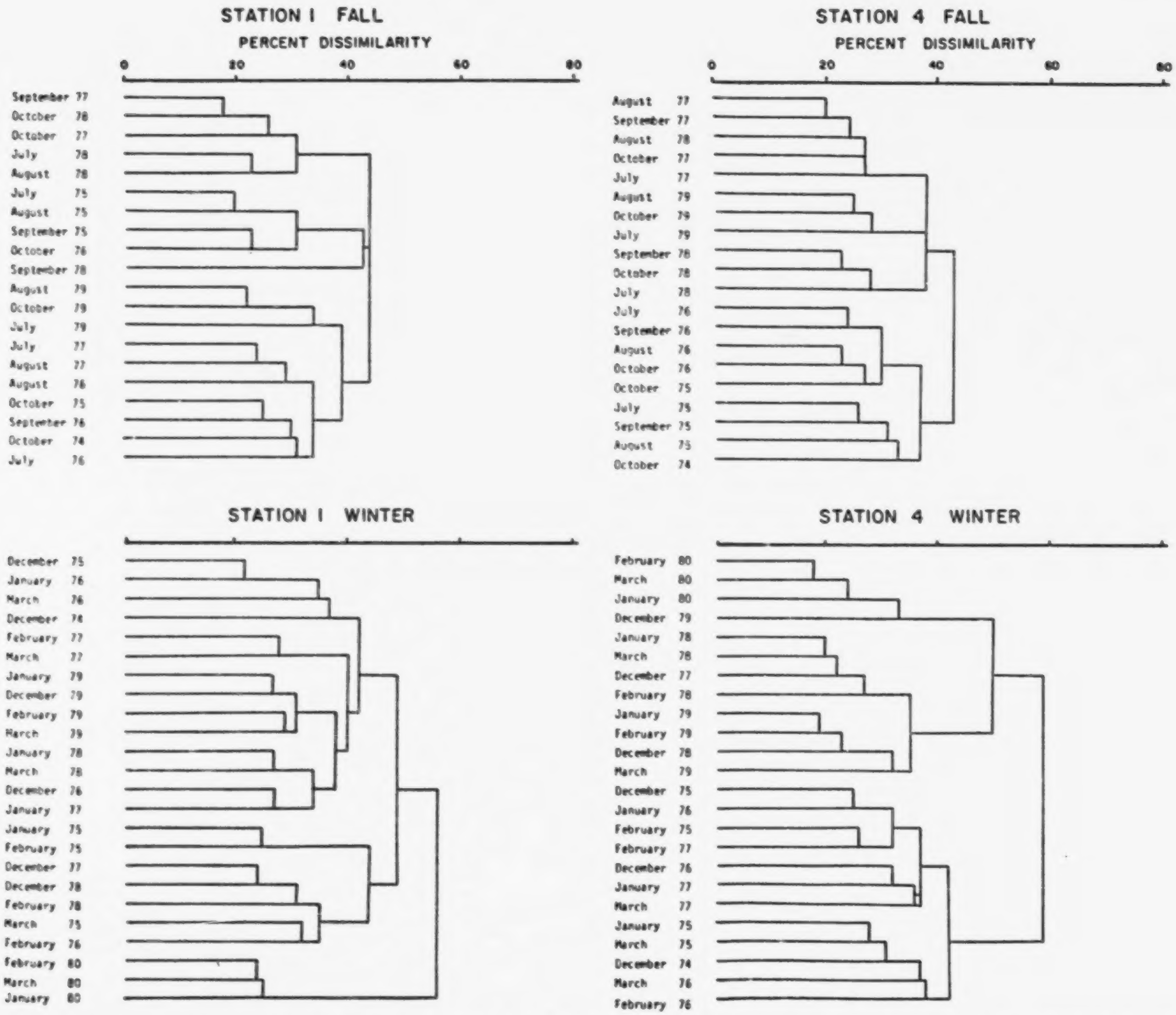

Figure 7. Dendrograms for Stations 1 and 4 illustrating cluster analysis results of infaunal species composition evaluation for all fall and winter periods during the Corpus Christi Bay study.

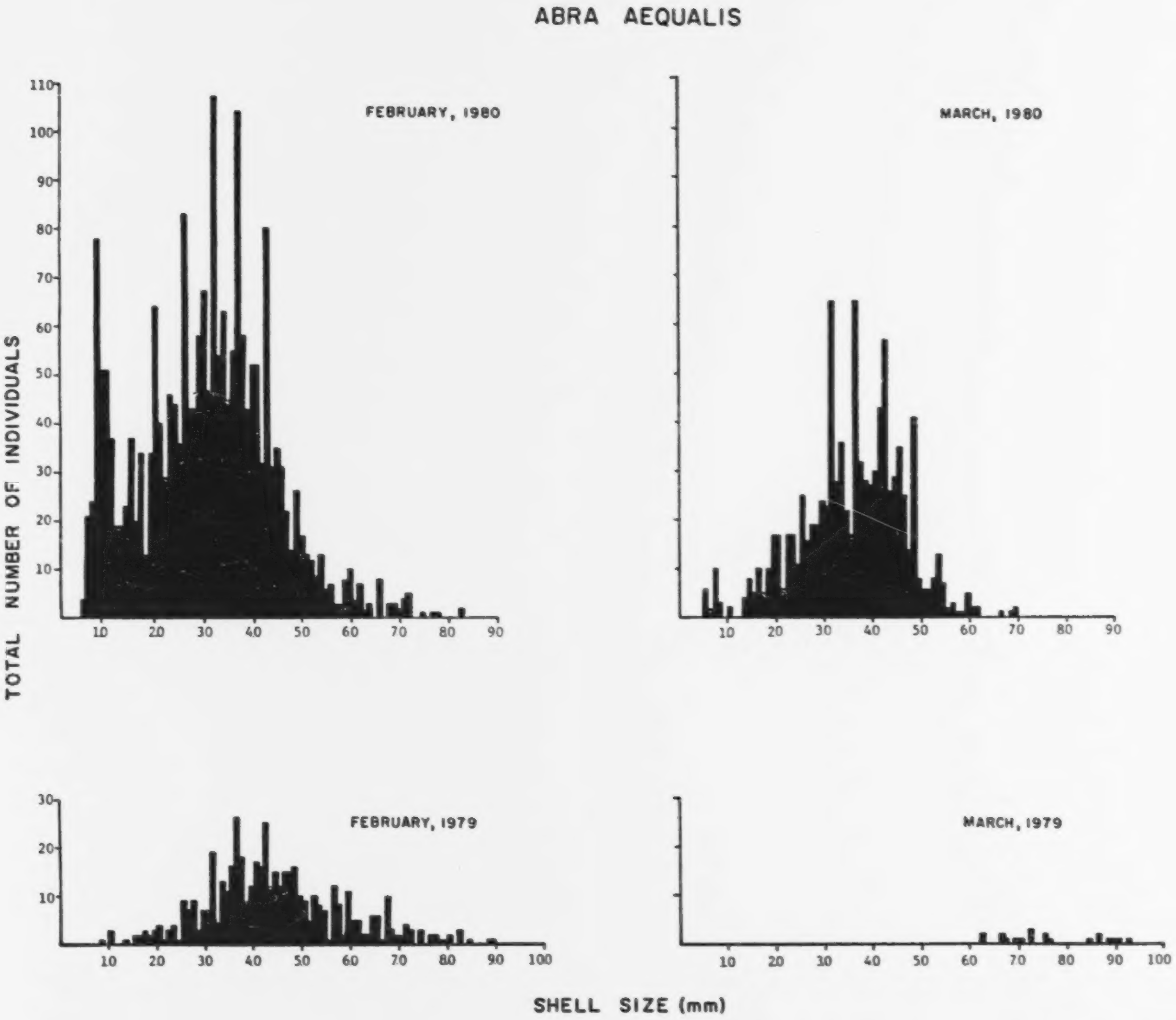

Figure 8. Size class distribution comparisons for populations of Abra aequalis during February and March 1979 and February and March 1980.

In addition to the population densities being much greater in 1980, the size class structure is slightly different. There appears to be a smaller mean size class for the 1980 collections suggesting a slower growth rate. Also obvious from Figure 8 is that while the population was almost depleted in number by March 1979, probably from predation, the March 1980 population was still quite dense and in fact this population sustained itself through May 1980.

The preceding discussion of observations made on benthic infauna densities for Corpus Christi Bay after the intensive freshwater inflow event of September 1979 illustrates the magnitude of the effect this event had on the ecosystem. Standing stock (biomass) information for the benthos, however, makes it much easier to infer the importance of these changes to the other components of the ecosystem such as the shrimp populations which derive much of their nutrition from the benthos. Again, as with infaunal total density infaunal biomass exhibited a dramatic increase after the freshwater inflow event, with a similar short lag period (Figure 9). Much of this biomass rise was related to a tremendous increase in the productivity of several dominant bivalves in the study area such as Abra aequalis (Figure 8).

Unfortunately, we did not measure infaunal biomass prior to July 1979. Therefore, the historical pre-event collections do not have comparable data for this important variable. A direct proportion was established, however, between measured biomass and infaunal density for the collections after July 1979. This relationship is illustrated in Figure 10. The relationship differed slightly between the data for station 1 and the data for station 4. Therefore, two regression equations were established (Figure 10).

We used these regression equations to calculate total biomass for the benthic infauna between September 1974 and June 1979, using the measured values for total density. Thus, we were then able to determine the infaunal biomass over the entire study duration for the early fall and winter periods as we did for community structure evaluations (Figure 7). The results of these comparisons (Figure 11) illustrated again that there were no major differences in infaunal biomass for any of the early fall periods shown, including the fall of 1979 when the inflow event occurred. In contrast, however, winter 1980 exhibited extremely large increases in benthic standing stocks compared to any other winter shown in Figure 11. Again, this presentation of biomass changes during the winter of 1980 provides evidence linking these changes of the benthos directly to the freshwater inflow event which occurred several months previously.

DISCUSSION

The Corpus Christi Bay complex and associated waterways (e.g. Corpus Christi Channel) have not shown a dramatic shift in salinity concentrations extending over greater time periods than a diel cycle for more than a decade. Hurricane Beulah which impacted the bay-estuarine complex behind Mustang Island in 1967 was the last major natural disturbance to the south Texas coastline which significantly altered the salinity gradients of this system away from normal regimes. Although heavy rainfalls were observed for this area during 1972, the estuarine system had not totally recovered from the impact

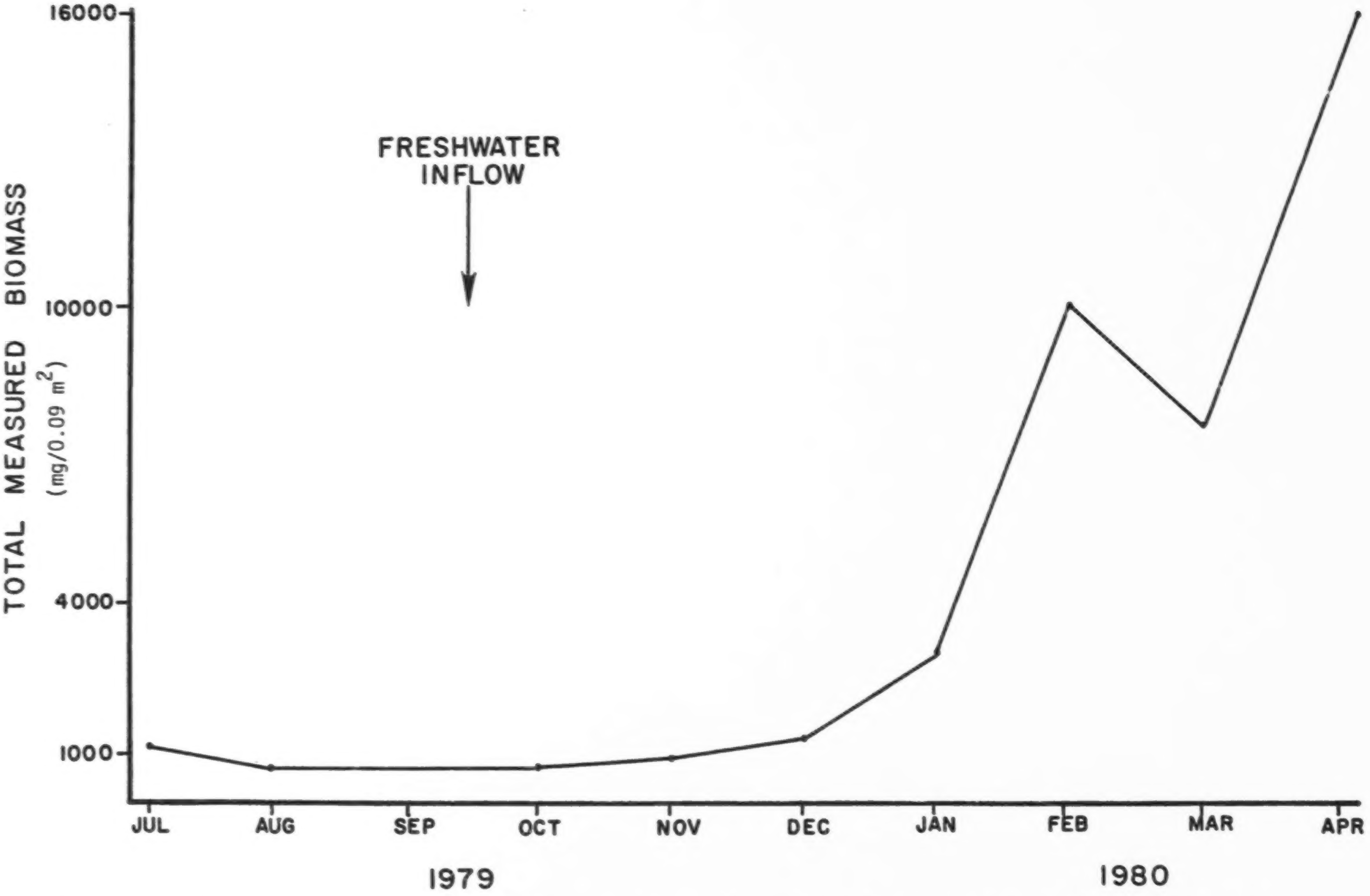

Figure 9. Plot of total mean infaunal biomass for Stations 1 and 4 between July 1979 and April 1980 in Corpus Christi Bay.

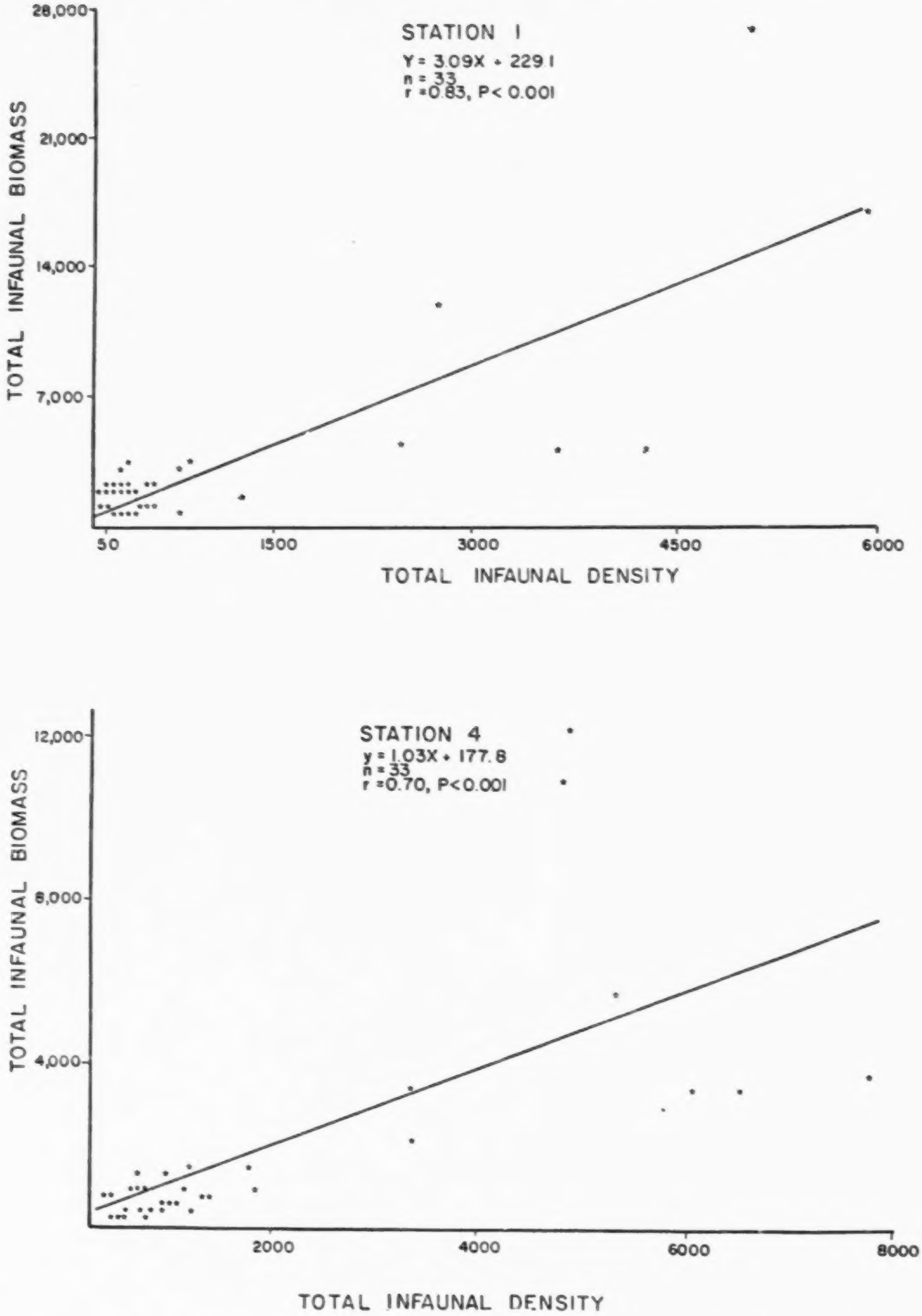

Figure 10. Linear regression best-fit curves for total infaunal biomass (mg/0.09 m^2) correlated against total infaunal density (individuals/0.09 m^2) at Stations 1 and 4 in Corpus Christi Bay.

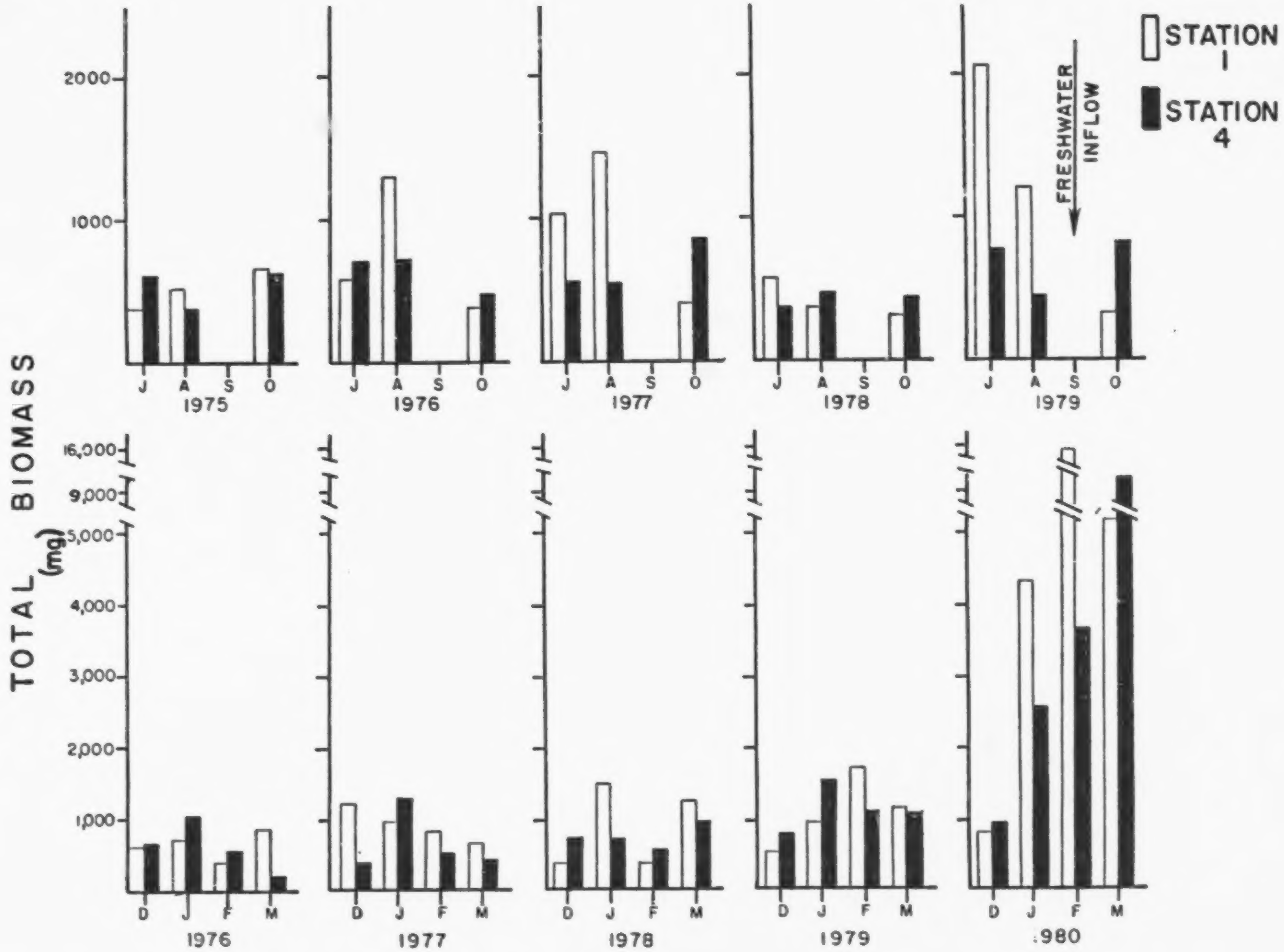

Figure 11. Histograms of total infaunal biomass for July - October, 1975-1979 and December - March, 1976-1980 for Stations 1 and 4 in Corpus Christi Bay. The biomass figures prior to March 1979 were calculated from the regression equations of Figure 10 using total infaunal density. After March 1979 biomass represents actual measured values.

of Beulah and the effects of these rains were therefore confounded and not totally interpretable.

The logic involved in focusing on the dynamics of populations on the sea floor for this study included the fact that because of the sedentary nature of these fauna, they represent a potential barometer indicating changes to the system unlike fish and many planktonic fauna which are relatively mobile and able to avoid adverse conditions prevailing over a preceding point. Furthermore, the benthos represents an important component of the estuarine ecosystem not only because of their trophic relationships with important fisheries but also because their activities and functioning within the sediments play a large role in material fluxes from the sediment sinks, including the nutrients which potentially drive the production of the system.

Unlike the few previous studies documenting accounts of effects of freshwater flooding on the estuarine benthos (Stone and Reish 1965; Boesch et al. 1976), the results of this study suggest that the inflow event had a positive impact on the functioning of the ecosystem. Stone and Reish (1965) reported mortalities of benthic invertebrates resulting from heavy rainfalls in the upper portions of some California estuaries. Wells (1961) reported effects of freshwater inflow from a series of successive hurricanes on oyster reef fauna of the Newport River estuary in North Carolina indicating mass mortalities and community structure changes. In a similar fashion, Thomas and White (1969) observed high invertebrate mortality following an unusually heavy spring thaw discharge into the Bedford River, Prince Edward Island.

In contrast to the above reports concerning small estuarine systems which do not have the volume of water to buffer against dramatic salinity changes, two studies in large estuaries also showed either high mortalities and community structure changes or that salinity changes simply determined the distribution of fauna. Boesch et al. (1976) observed the benthos in the lower Chesapeake Bay after Hurricane Agnes and found that many abundant species were eliminated from the shallow bottoms and several species were eliminated or reduced in abundance in the deeper waters after extensive freshwater intrusion into the estuary. Fradette and Bourget (1980) found that numbers of organisms and biomass decreased markedly from higher salinity areas to areas affected by freshwater inflows in the Gulf of St. Lawrence.

In the present study, from the cluster analysis results it would appear that community structure changes had occurred after freshwater inflow (Figure 6 and 7). In fact a few species did occur which had not been present previously increasing the number of species present in the bay (Figure 4). The most striking benthic changes that occurred, however, were the tremendous increases in densities (Figure 4) which had a profound effect on the clustering techniques employed. The dominant fauna did not disappear or change, as was observed in other studies. These fauna simply increased their production of biomass and numbers to records never observed before, in respect to the historical data base.

There is a possibility that in the previous studies cited above, either because of the smallness of the estuary or becuase the salinity changes after freshwater inflow were so dramatic (Boesch et al. 1976) that the impact to the system was deleterious. Corpus Christi Bay is a hypersaline estuary and the events described here included measured changes in salinity from the normal 25 to 30 ppt down to 11 ppt at one point in the bottom of the channel. This change may not have been sufficient to produce the same negative impact to the system as observed in other studies.

We conclude from this study, however, that periodic freshwater inflows to the Corpus Christi Bay ecosystem are extremely important in maintaining productivity of the ecosystem. We hypothesize that the freshwater inflow represents an increase in nutrients to the estuarine habitat which is then reflected by and increase in primary production of the system. Much of this increased primary production is ultimately diverted to the benthos (Flint and Rabalais 1981) and ultimately stimulates increased benthic infaunal production, representing additional food supplies to many of the important area fisheries such as shrimp. The lag time observed in this study between the inflow event and changed dynamics of the benthos is represented by dynamics in the lower trophic levels that must occur before the events are reflected by the benthos.

Therefore, from the data presented above, we feel that the kind of freshwater inflow observed during September 1979 is definitely beneficial to the entire estuarine ecosystem. The significance of documenting the effects within the Corpus Christi Bay system are obvious. Environmental managers in this area are constantly faced with decisions involving freshwater resources and effects to the estuary, related to the regulation of their flows. In addition, since the benthos is included in the trophic webs involving many of the important fisheries of the area, such as shrimp, the indirect effect to the fishery, reflected by future catch statistics correlated to the heavy freshwater inputs, and their effect to the benthic populations provide sound information to further test some of the models developed by environmental managers in recent years (Martin et al. 1980). We feel that this information on the benthos provides a missing link in the correlation observed between freshwater inflow and shrimp statistics.

LITERATURE CITED

Boesch, D.F.; Diaz, J.; Virnstein, R. W. Effects of tropical storm Agnes on softbottom macrobenthic communities of the James and York estuaries and the lower Chesapeake Bay. Chesapeake Sci. 17:246-259; 1976.

Day, J.S.; Field, J.G.; Montgomery, M. Use of numerical methods to determine the distribution of benthic fauna across the continental shelf of North Carolina. J. Animal Ecol. 40:93-126; 1971.

Downing, J.A. Aggregation, transformation and the design of benthos sampling programs. J. Fish. Res. Board Can. 36:1454-1463; 1979.

Flint, R. W., Rabalais, N.N. Environmental Studies of a marine ecosystem: south Texas outer continental shelf. Austin, Texas: Univ. of Texas Press; 1981:235p.

Flint, R. W.; Younk, J.A. Estuarine benthos: Long-term community structure variations, Corpus Christi Bay, Texas. Estuaries. [1981] in press.

Fradette, P.; Bourget, E. Ecology of benthic epifauna of the estuary and Gulf of St. Lawrence: factors influencing their distribution and abundance on buoys. Can. J. Fish. Aquat. Sci. 37: 979-999; 1980.

Lance, G. N.; Williams, W.T. A general theory of classificatory sorting strategies. I. Hierarchical systems. Computer J. 9:373-380; 1967.

LLoyd, M.; Ghelardi, R.J. A table for calculating the "equitability" component of species diversity. J. Animal Ecol. 33:217-225; 1964.

Martin, Q.; Powell, G.; Thorn, G.; Chang, G.; Belaire, S.; Goldstein, A.; Taneman, G. Lavaca-Tres-Palacios Estuary: A study of influence of freshwater inflows. Austin, TX: Texas Dept. Water Resources; Pub. #LP-106; 1980.

Mills, E. L.; Fournier, R.O. Fish production and the marine ecosystem of the Scotian Shelf, eastern Canada. Mar. Biol. 54: 101-108; 1979.

Pielou, E.C. Shannon's formula as a measure of specific diversity: its use and misuse. Am. Naturalist 100:463-465; 1966.

Scheefe, H. The analysis of variance. New York: Wiley; 1959.

Stone, A.N.; Reish, D.J. The effect of freshwater runoff on a population of estuarine polychaetous annelids. Bull. So. Calif. Acad. Sci. 64:111-119; 1965.

Thomas, M.L.H.; White, G. N. Mass mortality of estuarine fauna at Bideford, P.E.I., associated with abnormally low salinities. J. Fish. Res. Board Canada 26: 701-704; 1969.

Wells, H.W. The fauna of oyster beds with special reference to the salinity factor. Ecol. Monogr. 31:239-266; 1961.

THE EFFECTS OF FLOODS ON THE ZOOPLANKTON ASSEMBLAGE OF SAN ANTONIO BAY, TEXAS DURING 1972 AND 1973

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ABSTRACT

Plankton tows and hydrographic measurements were taken encompassing a single flood in 1972, and three floods in 1973 in San Antonio Bay. The shallow bay was rapidly flushed by influx of flood waters as was indicated by reductions in salinity and in the densities of the dominant species, *Acartia tonsa*. Floods replaced the typical estuarine zooplankter (*Balanus* sp. nauplii, *Oithona colcarva*, *Paracalanus crassirostris*, *Oikopleura* spp., and the cyphonautes larvae of *Membranipora* sp.) with the freshwater ones (*Diaptomus* spp., *Cyclops* spp., *Arcella discoides*, *Moina* sp., *Diaphanosoma* sp. and other cladocerans). During the 1972 flood, total zooplankton densities fell from 10,800/m^3 before the flood to 3,400/m^3 after the flood, but they increased rapidly when the river flow returned to base level. After the three floods in 1973, a cumulative decrease in total density of over two orders of magnitude was found. There had been insufficient time to reestablish preflood densities between each flood. The rapidity with which densities were re-established and the areas in which these increases were first found indicates the majority of the density changes were due to influx of zooplankton-rich bay water from Espiritu Santo Bay, rather than from population explosion by surviving refuge populations. It is important to note that the seasonal occurrence of a flood may severely reduce the survival of a bay's annual recruitment of economically important species whose larval stages are members of the zooplankton or which depend on zooplankton as food. It is also important to note the interdependency of these estuaries as currents flow carrying life from one into the next.

INTRODUCTION

Most estuarine plants and animals depend in some manner on fresh water from rivers and streams for their survival. The variability in quality and quantity of the freshwater inflow during a year and through several years can lead to dramatic environmental changes in an estuary, and thus in the organisms living there. With the increasing use of estuaries for various economic purposes it has become essential to know what to expect when certain environmental factors change. The objective of this paper is to describe the effects of floods on the zooplankton of a shallow estuary, San Antonio Bay, Texas.

MATERIALS AND METHODS

STUDY AREA

San Antonio Bay covers an area of about 305 km^2 and is located in the middle of the Texas coastline at latitude 28°20' North and longitude 96°45' West. It is a shallow bar-built estuary with an average natural depth of 1.5 m and contains many shallower oyster reefs and few places as deep as 3 m, however, recent shell dredging in the middle bay area has increased the depth in about 20 percent of this section to 4 m. Matagorda Island isolates San Antonio Bay from the Gulf of Mexico, and most salt water must flow into Matagorda Bay and through Expiritu Santo Bay before reaching San Antonio Bay. Fresh water from the combined flows of the San Antonio and Guadalupe Bay flow into upper San Antonio Bay (Figure 1). Annual evaporation slightly exceeds annual rainfall in normal years.

SAMPLING REGIME

Eleven sites were selected to represent the bay (Figure 2). To facilitate biological analyses with respect to salinity, these sites were partitioned into: Zone 1 = the upper bay, Zone 2 = the middle bay, and Zone 3 = the lower bay. Zooplankton was collected at each site twice per month by making a one-minute oblique tow with a #10 mesh (150 micron pore width) conical Nitex net which had a mouth diameter of 0.5 m and a length of 1.3 m. A flowmeter mounted in the net mouth measured the amount of water filtered on each tow. After each tow, the net was washed and the bucket's contents were preserved in 5 to 10 percent Formalin. Water temperature and salinity were taken immediately following the tow.

DATA COLLECTION

River flow rates were obtained for the rivers and creek from the U.S. Geological Survey annual records. Ten-day average river flow rates were calculated for each sampling time. Each average was based on the sum of the daily flow rates of each of the three tributaries for the day of sampling plus the nine previous days, i.e. the summation of 30 values divided by 10.

SAMPLE ANALYSIS

Methods similar to those used by Hopkins (1966) were used to analyze each zooplankton sample. A subsample taken with a Hensen-Stemple pipet and containing between 200 and 1,000 organisms was examined from each tow. Each organism was identified to the lowest taxon possible--usually to genus or species. Counts from the subsample were converted to numbers per cubic meter of bay water.

RESULTS AND DISCUSSION

THE SINGLE FLOOD OF 1972

Collections on May 4, before the flood, showed fairly high densities of zooplankton in Zone 1 and moderate levels in Zones 2 and 3 (Table 1). The composition of the zooplankton was typically estuarine for all zones at this time. Just before the flood there was a freshet which introduced sufficient fresh water to reduce the

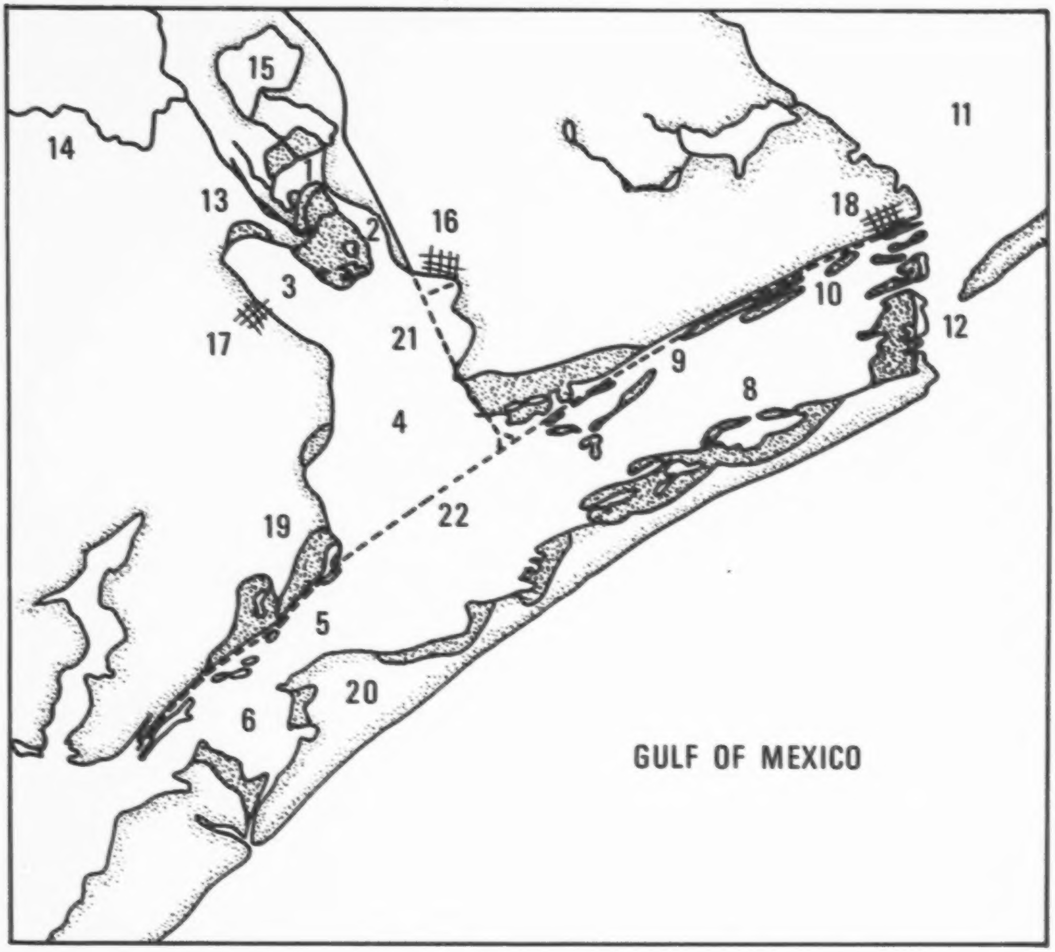
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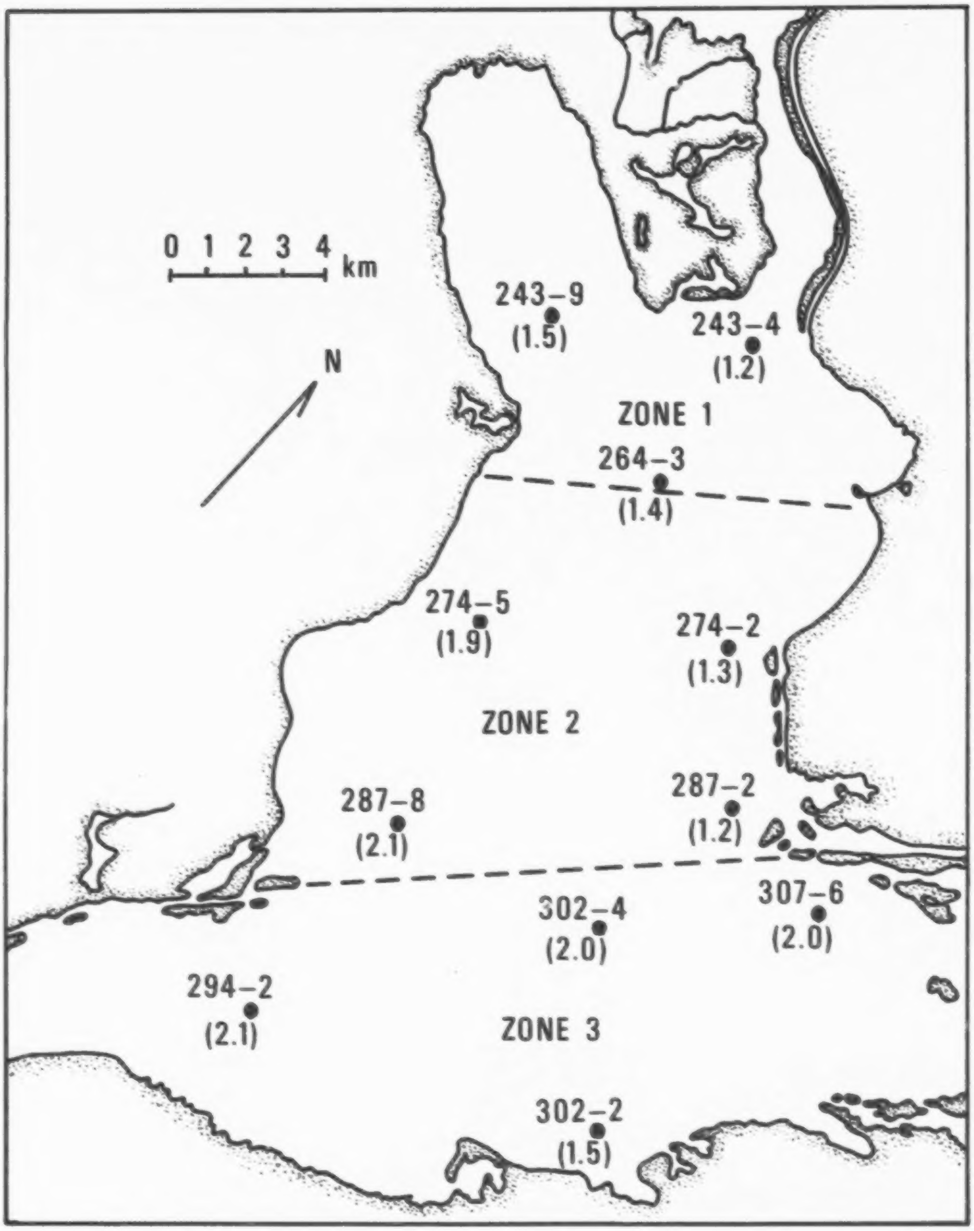
Figure 1. Components of San Antonio Bay System and vicinity. (1) Mission Lake (2) Guadalupe Bay (3) Hynes Bay (4) San Antonio Bay (5) Ayers Bay (6) Mesquite Bay (7) Cedar Bayou (8) Espiritu Santo Bay (9) Shoalwater Bay (10) Barroom Bay (11) Matagorda Bay (12) Pass Cavallo (13) Guadalupe River (14) San Antonio River (15) Green Lake (16) Seadrift, Texas (17) Austwell, Texas (18) Port O'Connor, Texas (19) Aransas Wildlife Refuge (20) Matagorda Island (21) Victoria Barge Canal (22) Intracoastal Waterway.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243–9
(1.5)
243–4
(1.2)
ZONE 1
264–3
(1.4)
274–5
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274–2
(1.3)
ZONE 2
287–8
(2.1)
287–2
(1.2)
302–4
(2.0)
307–6
(2.0)
294–2
(2.1)
ZONE 3
302–2
(1.5)

Figure 2. Collection sites in San Antonio Bay, Texas. Depths are given in meters in parenthesis.

Table 1. Zooplankton densities (individuals/m^3) before and after flood of May 1972 in San Antonio Bay, Texas. The contribution of freshwater taxa are delineated.

Date	ZONE 1			ZONE 2			ZONE 3		
	Total	Freshwater		Total	Freshwater		Total	Freshwater	
		(No.)	(%)		(No.)	(%)		(No.)	(%)
19 April	17611	7	0.0	10505	0	0.0	24300	0	0.0
4 May	19527	263	1.3	6122	0	0.0	6859	0	0.0
FLOOD..........									
23 May	3882	2116	54.5	4475	758	16.9	1757	757	43.1
7 June	851	66	7.8	11563	42	0.4	8460	74	0.9
22 June	584	344	58.9	21768	11	0.1	20390	0	0.0
6 July	5691	150	2.6	25211	136	0.5	34995	+	0.0
20 July	20001	35	0.2	12798	0	0.0	14093	0	0.0

average salinity in Zone 1 to about 7 parts per thousand. Total zooplankton density in Zone 1 increased slightly over its value at the previous sampling (19 April), but it decreased in both Zones 2 and 3. A few common freshwater zooplankters such as Cyclops sp., Diaptomus sp., and cladocerans were introduced into Zone 1, but no freshwater-related changes in diversities were found in the zooplankton of Zones 2 and 3 at this time (4 May).

The flood began on May 8, peaked on May 16, and had decreased to a freshet level by the sampling trip on May 23. Salinities in all zones had fallen to between 1 and 4 parts per thousand. Several changes had occurred in the zooplankton, and total zooplankton densities in Zones 1-3 had decreased to 20, 73, and 26 percent, respectively, of what they had been 19 days earlier. The percent of the total density contributed by taxa of freshwater origin had increased from 1.3 to 54.5 percent in Zone 1, and from 0 to 17 percent and 43 percent for Zones 2 and 3, and most of the dominant taxa in all three zones were of freshwater origin (Table 2).

By the collection time of June 7, the river flow rate had decreased to only 5 percent of the maximum flood flow rate, but the river rate was still slightly elevated above base flow rate. Salinity remained depressed in Zone 1 and increased only very slightly in Zones 2 and 3. Zooplankton densities were now even lower in Zone 1, but they had doubled in Zone 2 and had quadrupled in Zone 3. Contributions by taxa of freshwater origin to these densities were down to 7.4, 0.4, and 0.9 percent for Zones 1 to 3, respectively, and only in Zone 1 were they representing about half of the dominant taxa (Table 3). Diversities in all zones were lower than during the previous sampling. The percent of the diversity contributed by freshwater taxa was also lower, but it was still between 44 and 18 percent.

Freshwater inflow increased to freshet levels again on June 19, just a few days prior to sampling. Salinity remained at about 1.5 parts per thousand in Zone 1, but slight increases in salinities to about 6 and 10 parts per thousand were found in Zones 2 and 3 respectively. Densities reached a low in Zone 1 at $584/m^3$, but increased in Zones 2 and 3 to above $20{,}000/m^3$. Freshwater taxa accounted for virtually nothing in Zones 2 and 3. Diversity increased in Zones 1 and 2 but not in Zone 3. Freshwater taxa accounted for 54 percent and 12 percent of the diversity in Zones 1 and 2 respectively; none was found in Zone 3. All of the dominants in Zone 1 were of freshwater origin except Acartia tonsa.

River flow rate continued to decrease after the spike in late June, and salinity in Zone 1 finally increased to 2.5 parts per thousand at the time of the sampling on July 6, but it remained unchanged in Zones 2 and 3. Zooplankton densities increased an order of magnitude in Zone 1 and also increased again in Zones 2 and 3. Contributions by freshwater taxa to the density in Zone 1 decreased to about 3 percent and they increased in Zone 2 to 0.5 percent. Diversity decreased by almost half in Zone 1, just slightly in Zone 2, and

Table 2. Zooplankton diversities (number of taxa) before and after flood of May 1972 in San Antonio Bay, Texas. The contribution of freshwater taxa are delineated.

Date	ZONE 1			ZONE 2			ZONE 3		
	Total	Freshwater		Total	Freshwater		Total	Freshwater	
		(No.)	(%)		(No.)	(%)		(No.)	(%)
19 April	39	3	7.7	51	0	0.0	56	0	0.0
4 May	33	8	24.2	39	0	0.0	30	0	0.0
FLOOD..									
23 May	51	34	66.7	40	20	50.0	48	18	37.5
7 June	32	14	43.8	26	8	30.8	34	6	17.6
22 June	44	24	54.5	40	5	12.5	31	0	0.0
6 July	26	4	15.4	35	6	16.7	31	1	3.2
20 July	38	7	18.4	32	0	0.0	25	0	0.0

Table 3. Composition of the zooplankton community in each zone before, during, and after the May 1972 flood in San Antonio Bay, Texas. Each zone's composition is represented by its 12 most abundant taxa. * indicates taxa of freshwater origin. Surface and bottom salinities (o/oo) are given for each zone on each date.

	ZONE 1	ZONE 2	ZONE 3
Date: 7 June 1972			
Surface:	1.5	4.7	5.8
Bottom :	1.7	5.3	6.1
	Acartia tonsa	Acartia tonsa	Acartia tonsa
	Asplanchna sp.	Balanus sp. nauplii	Balanus sp. nauplii
	Gastropod veligers	Paracalanus crassirostris	Pseudodiaptomus coronatus
	*Cyclops sp.	Cyphonautes larva *A	Paracalanus crassirostris
	*Sinocephalus sp.	Copepod nauplii	Cyphonautes larva *A
	Harpacticoids	Oithona colcarva	Oithona colcarva
	*Diaptomus spp.	*Cyclops sp.	Copepod nauplii
	*Arcella discoides	Polychaete larvae	Spionid larvae
	*Perissocytheridea sp.	Asplanchna sp.	Fish eggs
	Copepod nauplii	Epistylis sp.	Polychaete larvae
	Ergasilus sp.	Ergasilus sp.	*Brachionus quadridentatus
	Ostracods	*Brachionus quadridentatus	Bivalve veligers
Date: 22 June 1972			
Surface:	1.5	5.8	9.3
Bottom :	1.7	6.5	10.0
	Acartia tonsa	Acartia tonsa	Acartia tonsa
	*Ilyocryptus spinifera	Balanus sp. nauplii	Balanus sp. nauplii
	*Cyclopoids	Gastropod veligers	Spionid larvae
	*Ephemeropteran larva	Oithona colcarva	Copepod nauplii
	*Diaptomus spp.	Copepod nauplii	Pseudodiaptomus coronatus
	*Tropocyclops prasinus	Hemicyclops sp. copepodids	Gastropod veligers
	*Diaphanosoma sp.	Neopanope texana zoea	Oithona colcarva
	Brachionus plicatilis	Halicyclops fosteri	Bivalve veligers
	*Apocyclops panamensis	Spionid larvae	Callianassa sp. #1 zoea
	*Arcella discoides	Ergasilus sp.	Halicyclops fosteri
	*Rhabdocoel worm	Callianassa sp. #1 zoea	Gobiosoma bosci larvae
	*Moina micrura	*Ostracods, Cyprididae	Rithropanopeus harrisii zoea
Date: 6 July 1972			
Surface:	2.6	6.6	9.4
Bottom :	2.9	6.6	9.5
	Acartia tonsa	Acartia tonsa	Acartia tonsa
	Balanus sp. nauplii	Balanus sp. nauplii	Balanus sp. nauplii
	*Cyclops sp.	Copepod nauplii	Pseudodiaptomus coronatus
	Copepod nauplii	Paracalanus crassirostris	Tintinnopsis sp.
	Paracalanus crassirostris	Pseudodiaptomus coronatus	Oithona colcarva
	Gastropod veligers	Gastropod veligers	Copepod nauplii
	*Ostracods	Polychaete larvae	Fish eggs
	Pseudodiaptomus coronatus	Oithona colcarva	Bivalve veligers
	Asplanchna sp.	Ergasilus sp.	Gastropod veligers
	Harpacticoids	*Platyias quadricornis	Anchoa mitchilli larvae
	Ergasilus sp.	*Eucyclops sp.	Spionid larvae
	*Cyclopoids	Brachyuran zoea	Cyphonautes larva *A
Date: 20 July 1972			
Surface:	2.8	8.1	9.5
Bottom :	3.0	8.2	11.8
	Acartia tonsa	Acartia tonsa	Acartia tonsa
	Balanus sp. nauplii	Balanus sp. nauplii	Balanus sp. nauplii
	Gastropod veligers	Copepod nauplii	Oithona colcarva
	Copepod nauplii	Brachionus plicatilis	Copepod nauplii
	Spionid larvae	Mnemiopsis mccradyi	Cyphonautes larva *A
	*Arcella discoides	Gastropod veligers	Pseudodiaptomus coronatus
	Halicyclops fosteri	Favella panamensis	Balanus sp. cypris
	Bivalve veligers	Balanus sp. cypris	Mnemiopsis mccradyi
	Pseudodiaptomus coronatus	Cyphonautes larva *A	Spionid larvae
	Tintinnopsis sp.	Bivalve veligers	Paracalanus crassirostris
	Balanus sp. cypris	Pseudodiaptomus coronatus	Neopanope texana zoea
	Oithona colcarva	Paracalanus crassirostris	Brachionus plicatilis

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Table 3. Concluded.

	ZONE 1	ZONE 2	ZONE 3
Date: 19 April 1972			
Surface:	12.2	15.2	19.6
Bottom :	12.0	15.6	19.6
	Acartia tonsa	Acartia tonsa	Acartia tonsa
	Gastropod veligers	Balanus sp. nauplii	Oithona colcarva
	Balanus sp. nauplii	Oithona colcarva	Pseudodiaptomus coronatus
	Bivalve veligers	Uca sp. zoea	Oikopleura sp.
	*Ostracod #2	Tintinnopsis sp.	Paracalanus crassirostris
	Tintinnopsis sp.	Pseudodiaptomus coronatus	Fish eggs
	Balanus sp. cypris	Gastropod veligers	Cyphonautes larva #A
	Copepod nauplii	Bivalve veligers	Copepod nauplii
	Oithona colcarva	Balanus sp. cypris	Ophiopluteus larvae
	Spionid larvae	Spionid larvae	Balanus sp. nauplii
	Pseudodiaptomus coronatus	Paracalanus crassirostris	Balanus sp. cypris
	Paracalanus crassirostris	Copepod nauplii	Anchoa mitchilli larvae
Date: 4 May 1972			
Surface:	6.7	19.7	23.6
Bottom :	7.0	20.1	23.9
	Acartia tonsa	Acartia tonsa	Balanus sp. nauplii
	Gastropod veligers	Balanus sp. nauplii	Oikopleura sp.
	*Cyclops sp.	Paracalanus crassirostris	Acartia tonsa
	Balanus sp. nauplii	Cyphonautes larva #A	Ophiopluteus larvae
	Bivalve veligers	Oithona colcarva	Cyphonautes larva
	*Cladocerans	Bivalve veligers	Oithona colcarva
	*Diaptomus spp.	Gastropod veligers	Copepod nauplii
	Copepod nauplii	Brachyuran zoea	Fish eggs
	Ergasilus sp.	Oikopleura sp.	Paracalanus crassirostris
	Paracalanus crassirostris	Copepod nauplii	Bougainvillia sp.
	Cyphonautes larva #A	Harpacticoids	Bivalve veligers
	Balanus sp. cypris	Balanus sp. cypris	Polychaete larvae
Date: 23 May 1972			
Surface:	1.1	1.8	3.9
Bottom :	1.8	2.0	4.2
	Acartia tonsa	Acartia tonsa	Acartia tonsa
	*Cladocerans	*Cyclopoids	*Cyclopoids
	*Cyclopoids	*Diaptomus spp.	Oithona colcarva
	*Cyclops vernalis	*Calanoid (freshwater)	*Eurytemora affinis
	*Arcella discoides	*Arcella discoides	*Eurytemora sp.
	*Apocyclops panamensis	*Microcyclops sp.	*Arcella discoides
	*Diaptomus spp.	*Moina sp.	*Diaptomus sp.
	*Eurytemora sp.	*Diaphanosoma sp.	*Moina micrura
	*Brachionus quadridentatus	*Cladocerans	Gastropod veligers
	Tintinnids	*Cyclops sp.	Nematodes
	Copepod nauplii	Harpacticoids	*Diaphanosoma sp.
	*Ceriodaphnia sp.	*Cyclops vernalis	Balanus sp. nauplii

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remained unchanged in Zone 3. Freshwater taxa accounted for only 15 percent of the diversity in Zone 1, 16 percent in Zone 2, and 3 percent in Zone 3. The zooplankton throughout the bay was returning to its estuarine dominants with few exceptions.

Salinities were slightly higher in all three zones during the sampling on July 20, but river flow rate had not decreased from the previous sampling date. Zooplankton density had increased substantially in Zone 1, but had decreased by half in both Zones 2 and 3. A few freshwater taxa contributed to the zooplankton only in Zone 1. Diversity had increased only in Zone 1, and had fallen slightly in Zones 2 and 3. *Arcella discoides* was the only freshwater species to reach the dominance list, and it was in Zone 1. The ctenophore, *Mnemiopsis* mccradyi, reached the dominance list in both Zones 2 and 3, and should be considered as a possible cause for the decrease in zooplankton densities in these two zones.

The species and taxa which most characterize the estuarine zooplankton community were also most often found in the dominance tables because they contributed greatly to the densities in each zone and particularly to those in Zones 2 and 3. These species and taxa forming the estuarine zooplankton community in San Antonio Bay are *Acartia tonsa*, *Balanus* sp. nauplii, *Oithona colcarva*, *Pseudodiaptomus coronatus*, *Paracalanus crassirostris*, cyphonautes larvae of *Membranipora* sp., spionid larvae, polychaete larvae, and gastropod veligers. *Acartia tonsa* was usually very abundant, and is known to tolerate very low salinities (Conover 1956). Even the flood could not displace it from being the dominant zooplankter. Only during the winter and spring with salinities above 20 parts per thousand was *A. tonsa* often replaced as the dominant taxon by *Balanus* sp. nauplii.

Many of the typically estuarine species were replaced by species and taxa of freshwater origin during the flood (Table 3). The most characteristic of these freshwater taxa were the freshwater calanoids *Eurytemora affinis* and several species of *Diaptomus*; the freshwater cyclopoids *Cyclops* sp., *Eucyclops* sp., *Apocyclops panamensis* and *Microcyclops* sp.; the cladocerans *Moina micrura* and *Diaphanosoma brachyurum*; the rotifers *Brachionus quadridentatus*, B. *Calyciflorus* and *Platyias quadricornis*; and the protozoan *Arcella discoides*. There were many other taxa of freshwater rotifers, cladocerans, copepods, and insect larvae that entered the bay with floods and freshets, but most were found in low densities and frequencies.

Most of these freshwater species are characteristic of backwater areas (Ward and Whipple 1959; Cooper 1967) rather than the open river itself. These freshwater species' populations may have been dense locally, but when they were washed into the bay by the floods their densities were considerably lower than those of the estuarine zooplankters inhabiting the bay. The dilution and displacement of bay water by the fresh water of a flood creates a natural dilution of the estuarine zooplankton, and when the diluting water has relatively few zooplankters the result is a reduction in the total zooplankton density in the bay. This is what happened during the May flood.

Diversity, however, was increased in the bay because of the influx of freshwater species. The myriad of backwater localities along the tributaries allowed for many different species' populations to flourish, and during the flood they were washed down the rivers and into the bay. Initially, more freshwater species and taxa were added to the sampling sites than estuarine species were displaced or killed. Diversity declined after this initial increase probably because most of the freshwater zooplankton had already been carried down the river, and because flow rates declined so that fewer remaining plankters were carried into the bay.

It is evident that the zooplankton community in the bay was greatly changed by the flood and that the changes occurred within two weeks of the start of the flood, and probably much sooner. Re-establishment of the typical estuarine zooplankton community depends substantially on the reduction of river flow rates, and after flow rates fall below freshet levels, it can still take two months to re-establish the estuarine species in the upper bay. Only about one month was required to re-establish it in the lower and middle bay areas. In this specific case the east side of the bay was first supplied with higher salinity water from Espiritu Santo Bay which was rich in estuarine zooplankton. Many tidal cycles and their attendant circulation patterns were required to re-establish the estuarine zooplankton along the west side of the bay.

MULTIPLE FLOODS OF 1973

The species composition of the freshwater zooplankton that entered the bay with the river inflow was very much the same as found during the May 1972 flood. Diversity appeared to be regulated considerably by the amounts and rates of river inflow (Figure 3). During the first four months the diversity trend followed the river flow rate but was one sampling delayed (time lag effect). From the beginning of the June flood through the October flood, this relationship was no longer found. In spite of the decrease in river flow rate during the last of the year, diversity in all zones also decreased. Much of this decrease was due to the cold weather when many meroplankters are no longer found in bay waters.

The percentage of the diversity of each zone, contributed by taxa of freshwater origin, was greatly increased by the June and October floods (Figure 4), and these percentages were much higher for Zone 1 than for Zones 2 and 3. Percentages contributed by freshwater taxa in Zones 2 and 3 were similar and they varied together more closely than with that of Zone 1 during the entire year.

The total zooplankton density decreased an order of magnitude from the start of the year to the end, but it also decreased much lower at times between these end points (Figure 5). Total density showed an inverse relationship to river flow rate. The June and October floods each caused a decline in total density of nearly two orders of magnitude which was never completely regained through the rest of the year. The recovery time, or time required for the density of a zone to re-establish its preflood level, appeared to be between two weeks and a month, i.e. between one and two sampling trips. The recovery time depended on tides, circulation patterns, spawning rates and periods, and temperature.

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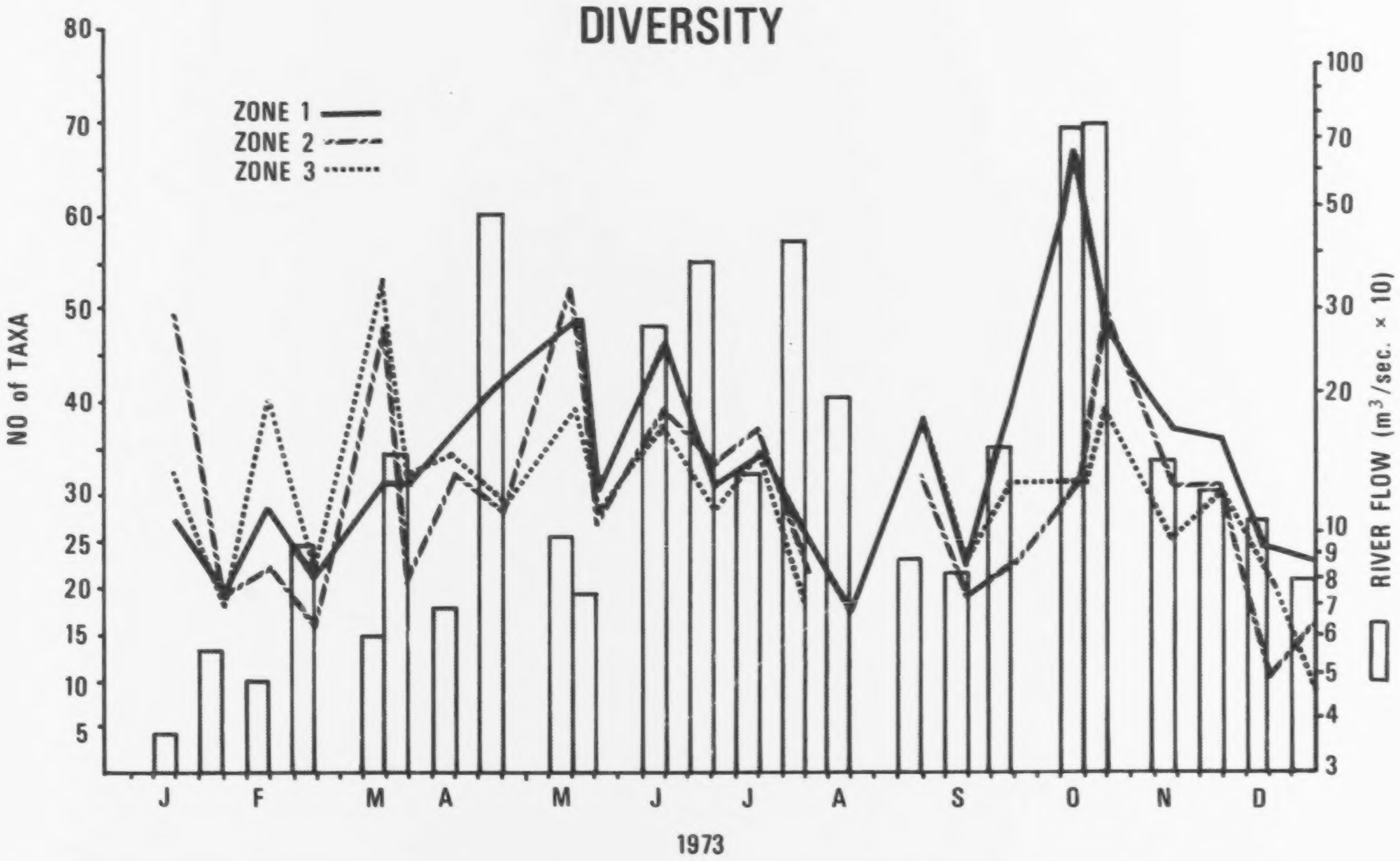

Figure 3. Zooplankton diversities for each zone in San Antonio Bay, Texas, during 1973, along with the 10-day average river flow rates for each sampling date.

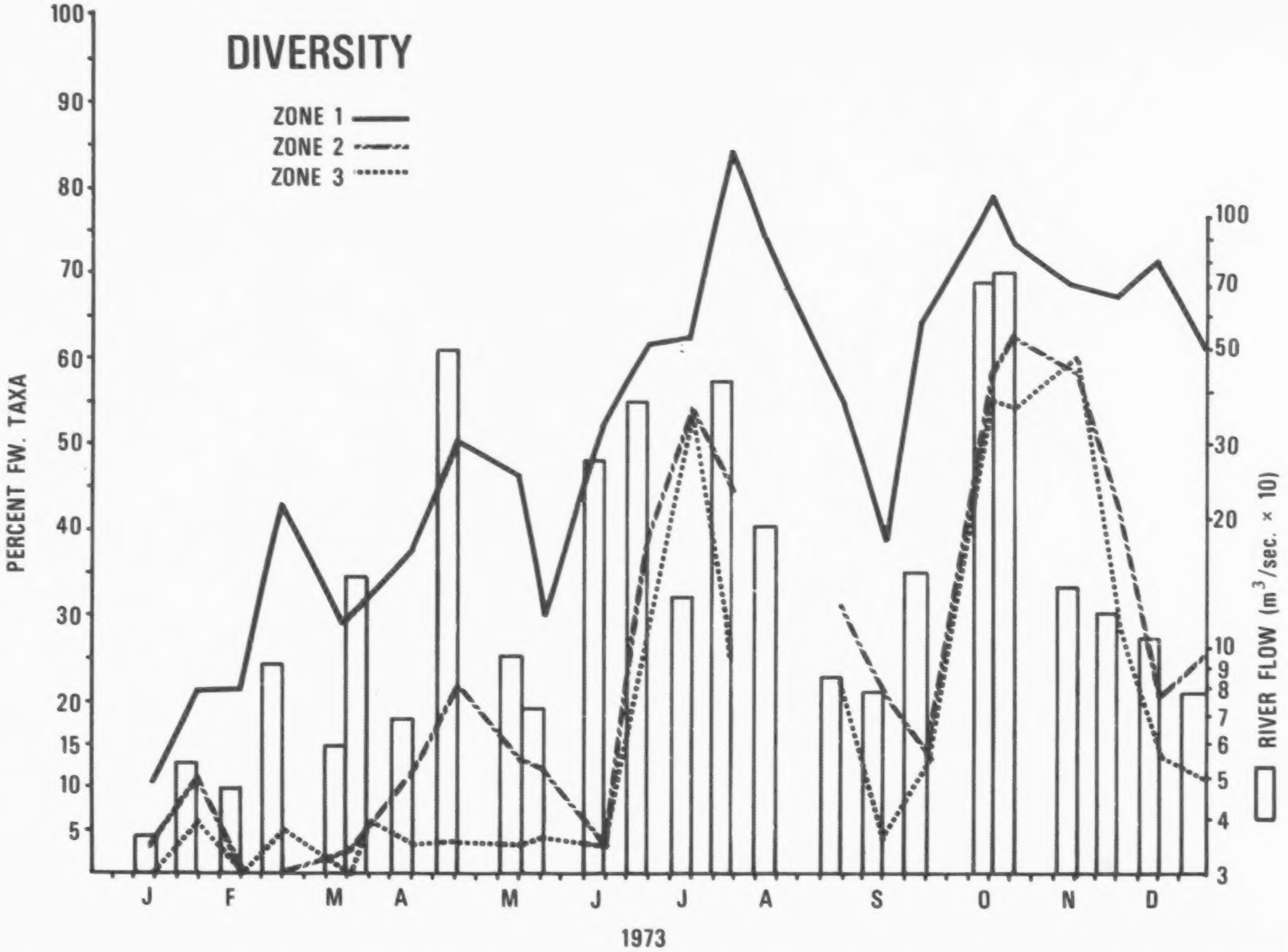

Figure 4. Percentages contributed by freshwater taxa to the diversity of zooplankton in each zone in San Antonio Bay, Texas, during 1973, along with the 10-day average river flow rates for each sampling date.

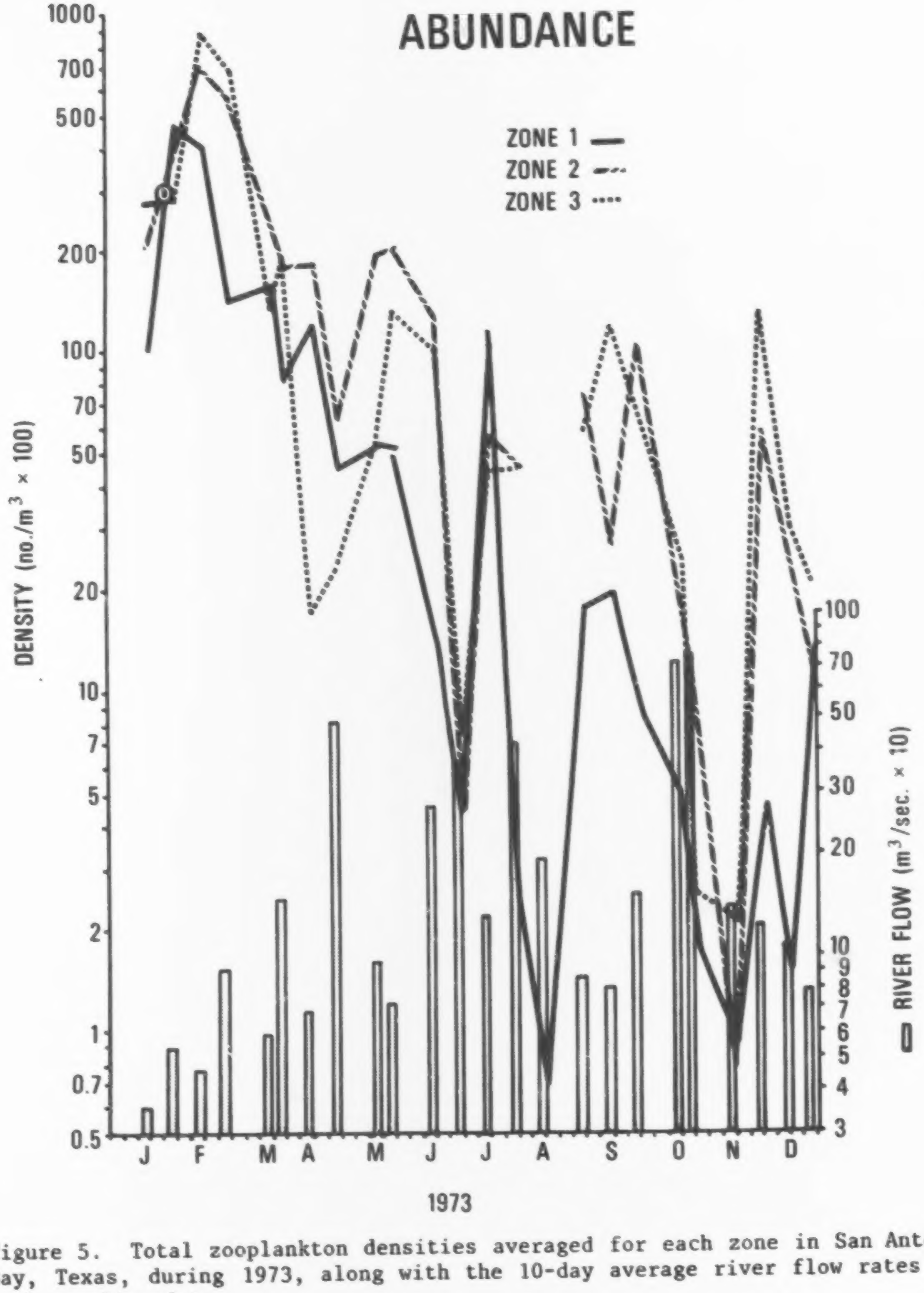

Figure 5. Total zooplankton densities averaged for each zone in San Antonio Bay, Texas, during 1973, along with the 10-day average river flow rates for each sampling date.

After each flood the zooplankton did recover, but in each case the recovery was incomplete. Densities were 10,000/m^3 to 20,000/m^3 before the April flood, decreased to 2,000/m^3 to 6,000/m^3 during the flood and recovered to 4,000/m^3 to 20,000/m^3 afterwards. The June flood arrived soon after this recovery, and densities declined again, this time to 400/m^3 to 800/m^3. Recovery to 4,000/m^3 to 12,000/m^3 occurred between the two major flow periods of this flood, and much of these densities were due to moderate populations of freshwater zooplankters. Zooplankton density in Zone 1 fell to only 64/m^3 after this second pulse of flood water. Equipment failure prevented sampling the other zones. After the flood, the densities recovered again to 1,800/m^3 to 11,000 /m^3, just slightly lower than the preflood values. At the start of the October flood the densities were about 850/m^3 to 9,500/m^3, and they declined to 70/m^3 at the end of the flood. Recovery after the flood was delayed in Zone 1, but it was rapid in Zones 2 and 3 with preflood densities being attained within a month.

Zooplankton of freshwater origin contributed greatly to the total density of each zone during these floods. Their contributions during the April flood were relatively minor, reaching only 33 percent of the total density in Zone 1 and much less for those in Zones 2 and 3 (Figure 6). Their contributions during the June flood were much greater, reaching 97 percent for Zone 1 near the middle of the flood, and 68 percent and 35 percent for Zones 2 and 3 respectively. Similar levels of contribution were found for each zone during the October flood. During all three floods, the freshwater taxa contributed a greater percentage to Zone 1 sooner and for a longer time than for the other zones which is reasonable considering Zone 1 is closest to the river mouth.

The cumulative effects of the floods during 1973 appear to be those of temporarily increasing diversity and decreasing density. Increased diversity in the bay as a whole is logical with the addition of freshwater taxa to those taxa already existing in the bay. Much of the decrease in density can be attributable to the relatively low densities of Balanus sp. nauplii in December 1973 versus the same time the previous year. This is a result of stressing or killing the adult barnacles with the very low salinities which existed in the bay for such an extended period. Matthews et al. (1975) noted relatively low standing crops of phytoplankton from early October through December 1973 as compared with the other periods. This paucity of food could have resulted in the poor spawn among the surviving barnacles, and thus the lower densities after the floods.

CONCLUSIONS AND RECOMMENDATIONS

Prolonged exposure of an estuary to fresh water such as was found during the floods in San Antonio Bay in 1973 may be considered damaging to the zooplankton and other fauna of the area on a temporary basis. Typical estuarine fauna are replaced by freshwater fauna and total zooplankton densities are usually greatly reduced during each flood. Because the 1973 type of flooding occurs once in 100 years or less, and because its effects are rapidly erased by influx of organisms and zooplankton from neighboring

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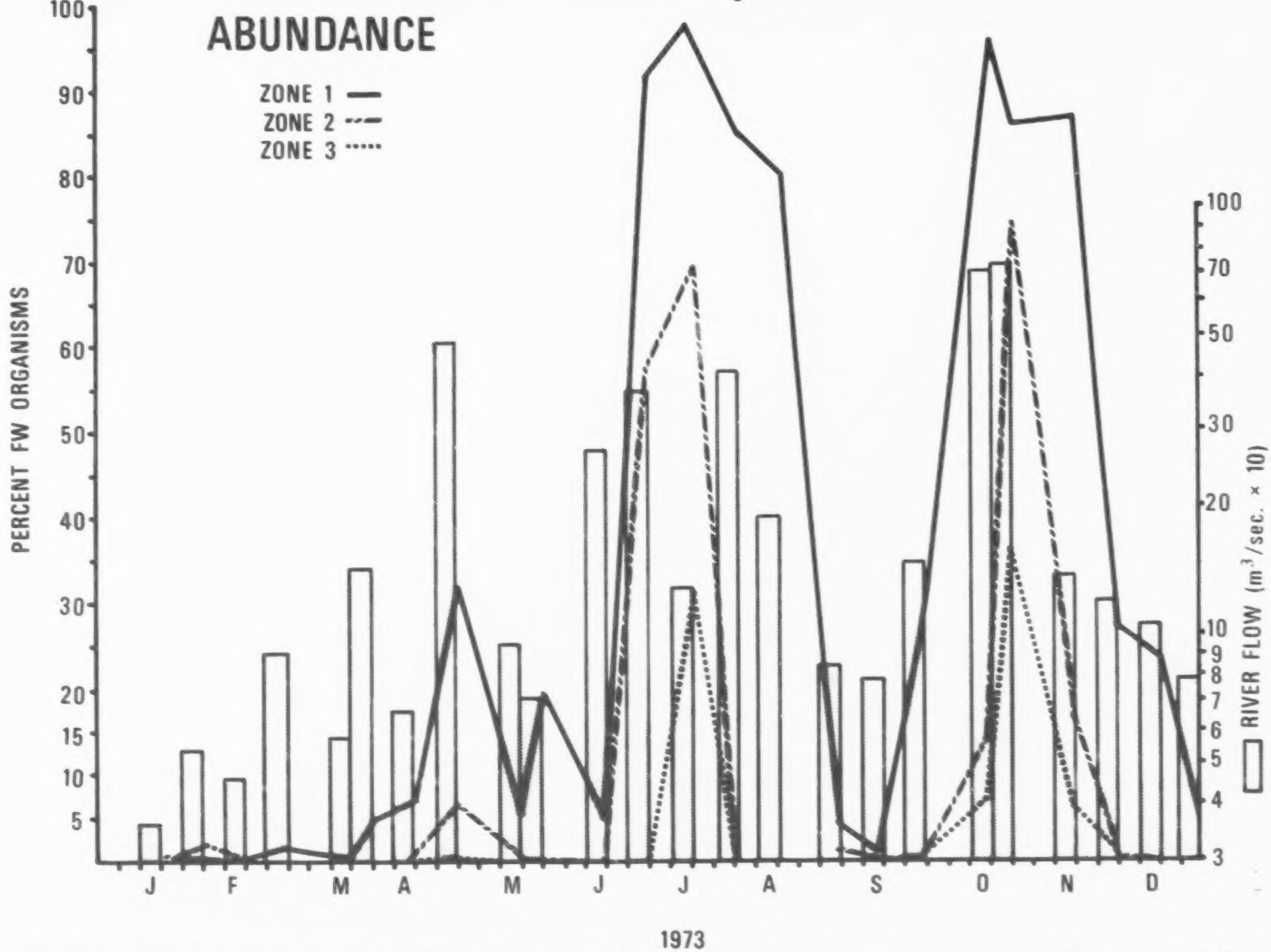

Figure 6. Percentages contributed by freshwater taxa to the total zooplankton densities averaged for each zone in San Antonio Bay, Texas, during 1973, along with the 10-day average river flow rates for each sampling date.

bays, there is no need to take preventive action.

The seasonal timing of floods can have important consequences. The occurrence of a flood when larvae of economically important species are in the zooplankton could significantly reduce future harvests in the bay by displacing or killing these larvae. At this time the importance of the influx of organisms and zooplankton from neighboring bays can not be overstated. Recruitment from these bays can assist in re-establishing these economically important species. Thus, it is necessary to define the circulation patterns between estuaries and to realize their interdependence so as not to delude ourselves into relinquishing one estuarine area to pollution as though it were an entity unto itself.

LITERATURE CITED

Conover, R.J. Oceanography of Long Island Sound, 1952-1954. VI Biology of Acartia clausi and A. tonsa. Bull. Bingham Oceanogr. Coll. 15:156-233; 1956.

Cooper, D.C. Ecological parameters concerning the zooplankton community of the San Antonio Estuarine System. Austin, TX: Univ. of Texas; 1967; 124p. Thesis.

Hopkins, T.L. The plankton of the St. Andrew Bay System, Florida. Publ. Inst. Mar. Sci. Univ. Tex. 11:12-64; 1966.

Matthews, G.A.; Marcin, C.A.; Clements, G.L. A plankton and benthos survey of the San Antonio Bay System, March 1972 to July 1974. Tex. Parks and Dept. Coastal Fish. Div. Final Report to the Tex. Water Devel. Board, 1975; 76p.

Ward, H.B.; Whipple, C.G. Freshwater biology. 2nd Ed. Edmondson, W.T. ed. New York: John Wiley and Sons, Inc. 1975; 1248p.

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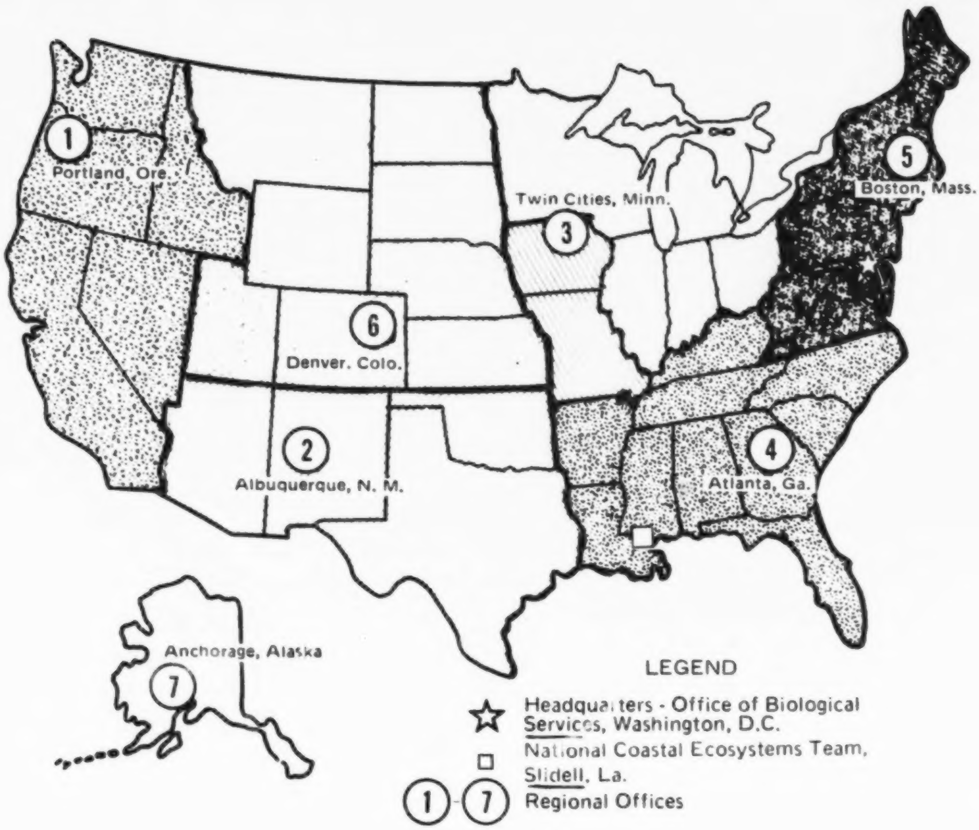
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